Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

CSAS | **SCCS**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Proceedings Series 2010/053 | **Compte rendu 2010/053**

Proceedings of the Newfoundland and Labrador Regional Atlantic Cod Framework Meeting: Reference Points and Projection Methods for Newfoundland cod stocks

November 22-26, 2010
St. John's, NL

Meeting Chairperson
Joanne Morgan

Editors
M.B. Davis
K. Skanes

Compte rendu de la réunion cadre sur la morue de la Région de Terre-Neuve et du Labrador : Points de référence et méthodes de projection pour les stocks de morue de Terre-Neuve

Du 22 au 26 novembre 2010
St. John's T.-N.-L

Président de réunion
Joanne Morgan

Éditeurs
M.B. Davis
K. Skanes

Fisheries and Oceans Canada / Pêches et Océans Canada
Science Branch / Direction des sciences
80 East White Hills Road
St. John's NL / St. John's, T.-N.-L.
A1C 5X1

February 2011 | **Février 2011**

Canada

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings include research recommendations, uncertainties, and the rationale for decisions made at the meeting. Proceedings also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

Avant-propos

Le présent compte rendu a pour but de documenter les principales activités et discussions qui ont eu lieu au cours de la réunion. Il contient des recommandations sur les recherches à effectuer, traite des incertitudes et expose les motifs ayant mené à la prise de décisions pendant la réunion. En outre, il fait état de données, d'analyses ou d'interprétations passées en revue et rejetées pour des raisons scientifiques, en donnant la raison du rejet. Bien que les interprétations et les opinions contenues dans le présent rapport puissent être inexactes ou propres à induire en erreur, elles sont quand même reproduites aussi fidèlement que possible afin de refléter les échanges tenus au cours de la réunion. Ainsi, aucune partie de ce rapport ne doit être considérée en tant que reflet des conclusions de la réunion, à moins d'indication précise en ce sens. De plus, un examen ultérieur de la question pourrait entraîner des changements aux conclusions, notamment si l'information supplémentaire pertinente, non disponible au moment de la réunion, est fournie par la suite. Finalement, dans les rares cas où des opinions divergentes sont exprimées officiellement, celles-ci sont également consignées dans les annexes du compte rendu.

Proceedings of the Newfoundland and Labrador Regional Atlantic Cod Framework Meeting: Reference Points and Projection Methods for Newfoundland cod stocks

November 22-26, 2010
St. John's, NL

Meeting Chairperson
Joanne Morgan

Editors
M.B. Davis
K. Skanes

Compte rendu de la réunion cadre sur la morue de la Région de Terre-Neuve et du Labrador : Points de référence et méthodes de projection pour les stocks de morue de Terre-Neuve

Du 22 au 26 novembre 2009
St. John's T.-N.-L

Président de réunion
Joanne Morgan

Éditeurs
M.B. Davis
K. Skanes

Fisheries and Oceans Canada / Pêches et Océans Canada
Science Branch / Direction des sciences
80 East White Hills Road
St. John's NL / St. John's, T.-N.-L.
A1C 5X1

February 2011

Février 2011

© Her Majesty the Queen in Right of Canada, 2011
© Sa Majesté la Reine du Chef du Canada, 2011

ISSN 1701-1272 (Printed / Imprimé)
ISSN 1701-1280 (Online / En ligne)

Published and available free from:
Une publication gratuite de :

Fisheries and Oceans Canada / Pêches et Océans Canada
Canadian Science Advisory Secretariat / Secrétariat canadien de consultation scientifique
200, rue Kent Street
Ottawa, Ontario
K1A 0E6

http://www.dfo-mpo.gc.ca/csas/

CSAS@DFO-MPO.GC.CA

Correct citation for this publication:

DFO. 2011. Proceedings of the Newfoundland and Labrador Regional Atlantic Cod Framework Meeting: Reference Points and Projection Methods for Newfoundland cod stocks; November 22-26, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2010/053.

TABLE OF CONTENTS

SUMMARY ..... **v**
INTRODUCTION **1**
MEETING PROCEEDINGS – TOWARDS REFERENCE POINTS **1**
DFO's decision making framework incorporating the precautionary approach 1
A review of frameworks from some other jurisdictions 3
Methodologies for setting LImit Reference Points (a review) 5
Methodologies for setting Limit Referece Points in Atlantic Halibut and Haddock 10
Limit reference points in other cod stocks 15
3Pn4RS Summary 15
4T Summary 16
3Ps Summary 17
3NO Summary 17
Limit Refernce Point for 2J3KL (Northern) Cod 18
Historical perspective on MSY-based reference points 18
Indices of Spawning Stock Biomass and Recruitment of Northern Cod from Survey Data 20
Survey model (SURBA+) for 2J3KL cod 20
SURBA+ for 2J3KL cod 21
SURBA+ Results 23
Stock-Recruitment (SR) 23
Ecosystem considerations for Limit Reference Points and projections: Exploring bottom-up and top-down drivers of Northern cod 36
DIscussion on setting Limit Reference points 39
Limit Reference Point for Northern cod 39
Can the approach for 2J3KL cod be used for other cod stocks? 39
General Conclusions on Reference Points 40
Conclusions on Reference Points for Newfoundland Cod Stocks 41
2J3KL (Northern) cod 41
3Ps cod 43
3NO cod 44
MEETING PROCEEDINGS – PROJECTION METHODS **45**
Population Metrics to be Considered for Projections 45
Agreed Approach to Projections 47
Methods for Combining Populations Into Designated Units (DUs) 48
REFERENCES **49**
APPENDIX 1 - TERMS OF REFERENCE **50**
APPENDIX 2 - AGENDA **52**
APPENDIX 3 - PARTICIPANTS **54**

SUMMARY

The purpose of this workshop was two-fold. The first objective was to discuss methodologies for the determination of reference points for Newfoundland cod stocks; and the second was to solicit views on methodologies for carrying out projections on Newfoundland cod stocks. Various methods were put forward and discussed/peer-reviewed during the meeting by participants from DFO Science in the Newfoundland and Labrador, Maritimes, and Quebec Regions. Participants from DFO Fisheries and Aquaculture Management provided the appropriate guidance for potential future applications (e.g. application of the Precautionary Approach; Recovery Potential Assessments) of the discussed approaches.

The main focus of the reference point portion of the meeting was the determination of a limit reference point (LRP) for 2J+3KL (northern) cod. In addition the existing LRP for 3Ps and 3NO cod were examined. Some guidance was also given on the setting of removal reference, upper stock reference and target reference points. The projection portion of the meeting agreed on how to treat the inputs and stochasticity in long term projections and on how to combine stocks to form designatiable units (DUs).

SOMMAIRE

Le but du présent atelier comporte deux volets. Le premier objectif est de discuter des méthodes de détermination des points de référence pour les stocks de morue de Terre-Neuve; le deuxième consiste à obtenir des points de vue sur les méthodes utilisées pour réaliser des projections sur les stocks de morue de Terre-Neuve. Au cours de la réunion, différentes méthodes ont été présentées et examinées/passées en revue par des participants provenant du secteur des Sciences des Régions de Terre-Neuve et du Labrador, des Maritimes et du Québec. Les représentants de Gestion des pêches et de l'aquaculture ont fourni les orientations appropriées pour d'éventuelles applications (p. ex. application de l'approche de précaution et évaluations du potentiel de rétablissement) des approches examinées.

La partie de la réunion concernant les points de références portait principalement sur la détermination d'un point de référence limite (PRL) pour la morue de 2J+3KL (nord). Le PRL actuel pour la morue de 3Ps et de 3NO a aussi été passé en revue. On a également fourni des orientations sur l'établissement de taux de prélèvement de référence, des points de référence supérieurs et des points de référence cibles. Pendant la partie de la réunion consacrée aux projections, on s'est entendu sur la manière de traiter les données d'entrée et la stochasticité dans les projections à long terme et sur la façon de combiner les stocks afin de former des unités désignables (UD).

INTRODUCTION

The meeting opened on November 22, 2010. The Chair, Dr. Joanne Morgan welcomed participants and did a round table of introductions. The Chair indicated that it was a small group of participants, i.e., primarily a science meeting with the participation of FAM and other regions who were all familiar with one another so there was an expectation of relative informality and productivity during the 5-day meeting.

A number of administrative details were covered by the chair, including relevant documents and presentations being available electronically on the shared drive for easy access during the meeting, as well as the requirement for those presenting to provide abstracts of their presentations to the Rapporteur (Dr. Ben Davis and Katherine Skanes) or the Chair as soon as possible after their completion to assist in timely preparation of the Proceedings report.

The meeting would endeavor to address those points laid out in the Terms of Reference (Appendix 1). Specifically, the purpose of the meeting was two-fold:

1. Limit reference points (LRP) - Develop a limit reference point for Northern Cod and discuss suitability of those existing for the other two cod stocks in Newfoundland.

2. Explore methodologies carry out projections cod stocks (and DUs) for the RPA meeting in February 2011; and discuss questions surrounding this exercise in anticipation of the meeting.

It was the intent for the first two days of the meeting to be allocated to reference points and the last three days to projections. However, it was the feeling that time would be allocated as required as the meeting progressed over the five days. There was one addition to the agenda – a presentation by Brian Healey, although it was accepted that the agenda also remain flexible as required. Since no SAR would be produced from this meeting, the timely completion of a Proceedings Document was expected to communicate the outcomes.

MEETING PROCEEDINGS – TOWARDS REFERENCE POINTS

Initial discussions aimed to describe the Precautionary Approach framework and consider methods used in different jurisdictions for setting limit reference points.

DFO'S DECISION MAKING FRAMEWORK INCORPORATING THE PRECAUTIONARY APPROACH

Presented by Peter Shelton

Summary

DFO's new Sustainable Fisheries Framework (SFF) provides policy for decision-making in Canadian fisheries. It incorporates existing policies for fisheries management, conservation and sustainable use, governance and economics with new and evolving policies using a phased-in approach. It also provides tools to monitor areas that need improvement and for reporting nationally on progress (Sustainability Checklist).

An important component of the SFF policy is "A fishery decision-making framework incorporating the Precautionary Approach". The decision-making framework document attempts to describe a general fishery decision-making framework for implementing a harvest strategy that incorporates the PA that can be applied annually to determine TACs or other measures to control harvests. The approach is based on the 3 Zone PA framework (Healthy, Cautious and Critical Zones). Zones are demarcated by reference points developed by Science and Fisheries Management.

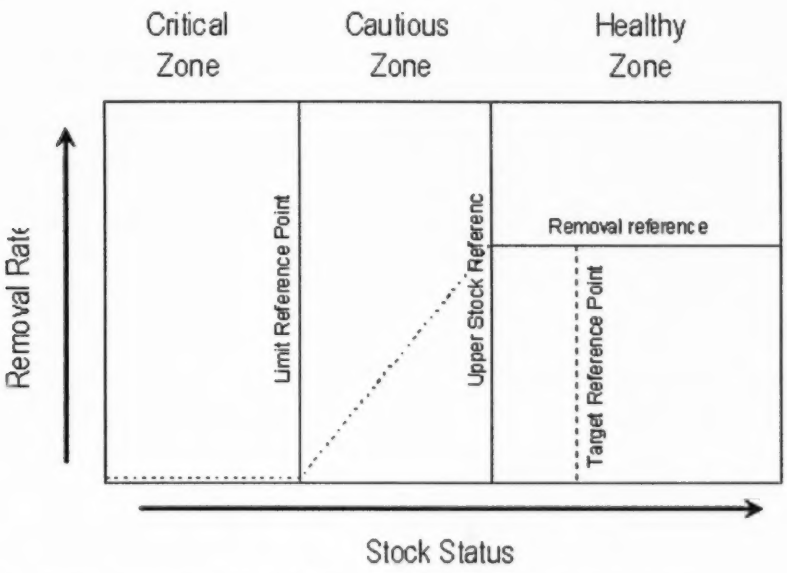


Figure 1. DFO's Precautionary Approach framework showing the reference points

The DFO decision-making framework document attempts to provide both policy direction and guidance on implementation. There are limitations in both areas. It does not provide clear policy direction in terms of objectives, process, timelines and performance evaluation. In terms of guidance it is not clear which parts of the document constitute a description of a best practice standard and which parts are examples of optional aspects that can be considered by regions in implementation of the policy. In comparison, the Harvest Strategy Standard for New Zealand Fisheries provides an example of a more explicit policy direction and implementation guidelines. The lack of clarity in the technical guidance may hinder regional implementation. Some important aspects of the new decision-making framework policy document are summarized below.

Uncertainty and risk - the decision-making framework document requires that both scientific uncertainty and uncertainty related to the implementation of a management approach must be explicitly considered. Uncertainty should be incorporated in the calculation of stock status and biological reference points.

Risk of preventable decline - in the Healthy Zone stock reductions resulting from management actions with a low probability of the stock falling to the Critical zone are tolerated. In the Cautious Zone near the Critical Zone there is a low tolerance for a risk of the abundance

declining from its current level. In the Critical Zone, conservation concerns are paramount and there is no tolerance for preventable declines.

Variation in productivity - should be taken into account when setting reference when this variation appears to be structured as periods of consistently high or low productivity. Reference points estimated from low productivity period should only be used when there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management. As long a time series as possible should be used in establishing reference points for a stock.

Best practice for determining reference points – two approaches are considered in the decision-making framework document, one based on stock-recruit analysis such as the spawning stock biomass giving 50% of the maximum estimated recruitment from a Beverton-Holt stock recruit model (BH50) and the other based on maximum sustainable yield (MSY) reference points. MSY-based reference points take into account both sources of stock production – recruits per spawner and spawner per recruit and could therefore be argued to be superior, although the DFO decision-making framework and advice from headquarters suggests that stock-recruit based reference points are preferred. Best practice for determining reference points in the context of the DFO framework requires further discussion by regional experts.

A REVIEW OF FRAMEWORKS FROM SOME OTHER JURISDICTIONS

Presented by Peter Shelton

Summary

The DFO decision-making framework incorporating the PA is similar to frameworks development by Northwest Atlantic Fisheries Organization (NAFO), USA, New Zealand and International Council for the Exploration of the Seas (ICES). These frameworks all attempt to restore stocks to healthy levels and to avoid depletion, generally through the application of predetermined harvest control rules. Some frameworks do not require a limit reference point to be defined (USA, ICES). Most frameworks are based on MSY-related reference points (USA, NZ, ICES) and provide clear explicit best-practice defaults (e.g. NZ and USA). Most frameworks require a time-constrained rebuilding plan to be implemented on an overfished or depleted stock, but differ with regard to the level of depletion at which the rebuilding plan is implemented. US and New Zealand have simpler and more transparent approaches to monitoring and reporting on sustainability across stocks nation-wide compared to the DFO Sustainability Checklist.

In the last few years the idea of managing by reference points and risk has come under increasing criticism. Typically, the state of the stock and the position of the reference point are both highly uncertain. Because of this it has been argued, and in some cases demonstrated by simulation studies, that simple feedback harvest control rules that respond directly to the size or trend in the surveyed or modelled stock, without considering reference points at all, outperform more complicated harvest control rules that vary the fishing mortality rate based on the estimated state of the stock relative to an estimated reference point. When simple feedback harvest control rules are adopted, the "true" simulated reference points can be used in the context of performance statistics to evaluate competing candidate harvest control rules.

Discussion

In considering the overview of the PA Framework as it exists in DFO and what other jurisdictions are using for the determination of reference points, several questions and ensuing discussions surrounding the associated topics arose during the presentation and ensuing plenary:

- With respect to the critical zone: are we trying to keep all sources of mortality at the lowest level including natural mortality? There is fishing mortality and other human impacts like seismic, eutrophication etc. that we can control.

- With respect to reference points under a different productivity level – does anyone know what this means? While there is some reference to it previously (see Mohn and Chouinard), this may not answer the present question. It was also noted that this issue might not be a concern in our lifetime since we may never see a high productivity state again.

- Is it the expectation that a reference point would result in a natural return or returns through management measures to a predetermined stock level? No clear answer was provided.

- When do you do rebuilding? It should do it half-way through the caution zone rather than at the threshold of the critical zone – this is one interpretation but it is logical to start before the critical point.

- What is the USR? Is it the bottom end of the "healthy zone"? It was felt that this is the target – interpreted as a SSB somewhere above the LRP, and also that the best advice for management in setting the USR is to base the limit on the stock recruit curve

Do we have a specific definition for a limit reference point? It was the feeling of the group that is hard to provide reference points if we do not know how terms are defined. Meanwhile, the definition in Annex A (from the presentation) is the best that people can apply for now; Annex B provides further guidance in the absence of data and analysis. In deciding what weight to provide the guidance in the annexes, it was noted that if the PA working group could not provide a definition, and the regions could not develop one, then we are bound by the advice in the Annexes for now.

In this, it was the suggestion of the Chair to first look at what other people have done to see if this provides a better path. Keeping in mind the framework and other practices, and the available data, the goal is to come up with a LRP for Northern cod. Early discussions indicate that no one will be delivering a simple answer or definition.

Considerations for moving forward with determining a reference point for Northern Cod was discussed, where options included:

- applying precedence or essentially what and how other jurisdictions used
- fitting stock recruit data to survey data
- application of annex A or annex B
- defining a new methodology of our own

It was noted that there is a requirement to know our own domestic framework and see where it fits with others so we know where we stand in relation to others. This framework is not entirely clear, but this is not unique.

In regards to other frameworks, it was noted, for example, 30, 40, 50 B_{msy} is used in other jurisdictions. This is a large range – and therefore International "best practice" may not be really helpful to this process. It would be useful to have a description of where some of this information came from rather than it being of uncertain sources. It would also probably be useful to have the US approach described in more detail, although this report is not easy to find.

It was pointed out that the guidelines state that as long as a time series as possible should be used in establishing reference points for a stock and that as a general rule the only circumstances when reference points should be estimated using only information from a period of low productivity is when there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management.

The group also noted that, internationally, limits are being downplayed while we are going to targets, i.e, the Canadian approach is still to use limits.

METHODOLOGIES FOR SETTING LIMIT REFERENCE POINTS (A REVIEW)

Presented by Daniel Duplisea

Summary

There are three general methods for determining limit reference points (LRP) for a stock:
1. stock recruitment
2. stock production and MSY
3. empirical and knowledge limits

Stock-recruitment methods

Stock recruitment methods require that one fit some kind of model to the data. These models could include well known models such as Ricker, Beverton-Holt or hockey stick or they can include data smoothing approaches. Once a model is selected and fitted, the LRP is set by a common method: the SSB giving 50% of the maximum R from the fitted model.

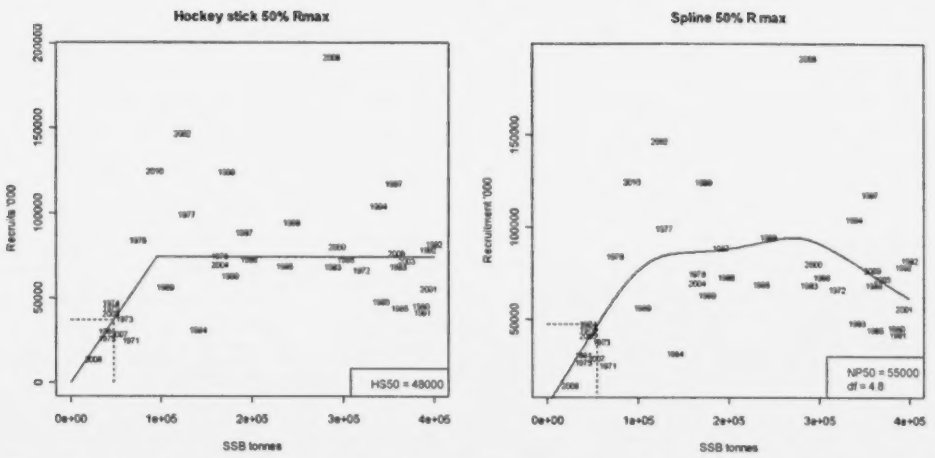


Figure 2. Hockey-stick (left panel) and spline-smoothed (right panel) curves fitted to mock SR data. Dashed lines represent the SSB giving 50% of maximum R from the fitted curve which is the LRP (lower right box of each panel).

Stock recruit fits should be tested for significance before they are used. Smoother fits should have a justification for the degree of smoothing either through reasoning or chosen by an objective methods such generalised cross validation. Any smoother should also make sense in terms of process. Parametric model fits could be done by a number of methods and maximum likelihood is a useful method while the error distribution needs to be justified.

Stock-production (MSY) methods

Stock production methods require that one determine the Bmsy for the stock, which is generally considered the lower boundary of the healthy zone or in some cases a target. 40% of Bmsy is a common convention used in Canada a means of setting the LRP though values from 25-50% of Bmsy have been used internationally.

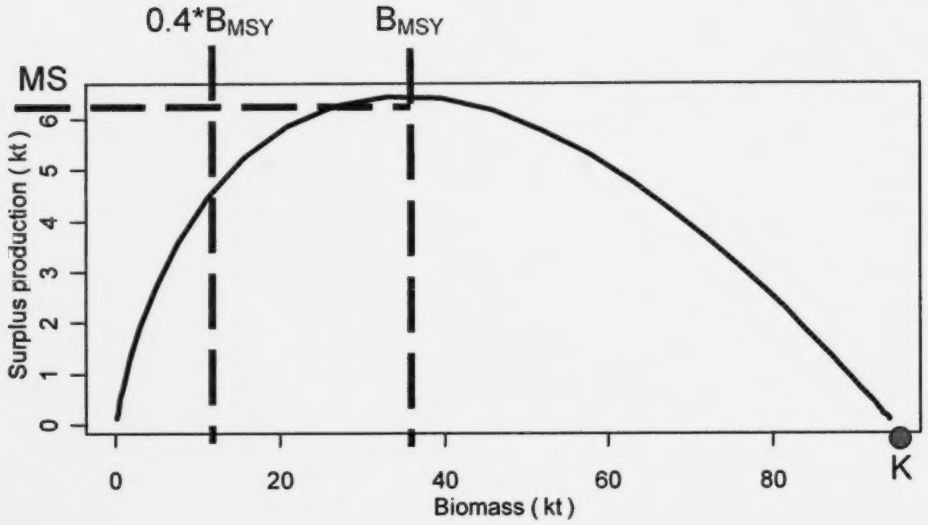


Figure 3. A surplus production curve with Bmsy and 40% Bmsy, which would be the LRP, for a mock fish stock obeying Fox production model dynamics.

Another means of choosing a LRP based on MSY is to link the LRP to fishing rate, and recovery time: choose the LRP to be the value that under a chosen set of conditions the SSB can recover to Bmsy in 10 years (or a time related to mean generation time of the stock) if fishing at Fmsy.

Empirical and knowledge limit methods

Empirical LRP methods would include points like Brec which the lowest observed SSB from which there has been a secure recovery. Not all stocks exhibit a Brec. Other empirical methods include the concept of knowledge limits or where ignorance begins. That is, if the LRP suggested by the two previous methods is below the lowest observed value, one is not actually certain of the stock dynamics in that area and therefore the LRP would default to the lowest point in the series. Furthermore, if one were choosing an LRP based on an SSB range where recruitment went to poor levels (serious harm), the LRP would be set at the larger of the two SSB points bounding the point of serious harm.

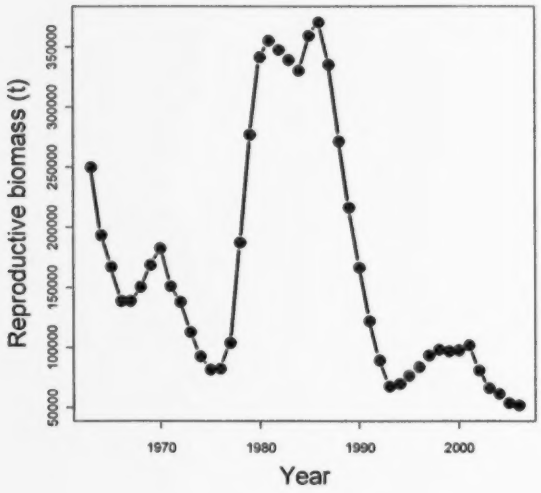


Figure 4. SSB series for 4T cod. In this case the empirically determined LRP is Brec which is the 1977 biomass of 75,000 t.

Issues with LRPs and the PA

There are arbitrary elements in setting LRPs and most reference points generally. Limit reference points are meant to describe the stock state below which serious harm is occurring. For this reason, it is a point to be avoided and it would be difficult to justify an LRP as a recovery point. LRPs are rarely, if ever, set with concepts of extinction risk in mind and they do not guarantee that extinction risk is low at the LRP though extinction is thought to be highly unlikely at the LRP.

Stock productivity may not be stationary thus leading to productivity regimes. It is not clear how we should deal with productivity regimes in terms of modifying the reference points. A productivity regime by definition is a longer term change in state rather than just random variation and this should be verified before one concludes they are in a new productivity regime.

Finally, it is not prescribed when a PA framework and LRPs should be re-evaluated. Certainly, an LRP would not be re-estimated each year or with the addition of a new year of data. It should be re-evaluated when there is a significant change in information or knowledge of stock which could include several years of data, a new model, important retrospective changes in data or some biological criteria.

Discussion

The Chair noted that it is nice to see a variety of approaches to understand that there are a number of ways to derive these points. Therefore, discussions of fitting the models is important. There is also the need to understand what the implications are of decisions of LRP based on the quality of the data and what the models are indicating.

Several issues related to the various methodologies presented were brought forward during plenary:

- non-stationarity exists in [some of] the methodologies. To this concern it was noted that the whole time series should be incorporated in the analyses – it is recommended but not always done in practice. Looking at patterns in residuals with time, although suggested during discussions, is not a remedy to this.

- measurement error in the stock axis has a large effect on the estimate of BH50. Small amount of error can lead to large deviations. A paper that describing this was supplied to participants [Cadigan, N.G. 2009. Sensitivity of common estimates of management parameters derived from stock-recruit relationships. Fish. Res. 96: 195-205. doi:10.1016/j.fishres.2008.11.003.

- if trying to fit curves to data that come only from a depleted stock, there is a risk that the LRP may be irrelevant

It was concluded that in terms of biases and measurement error in the stock axis, the idea of re-evaluating LRPs as more data becomes available is a good one.

In regards to extrapolation, it was discussed whether or not this should occur. While it was suggested at one point that this should not happen, it was also suggested that if the data is linear then your evidence of compensation would be beyond the data you have – then the upper level of the SSB may be a 'milestone' which you need to get above to reevaluate the LRP.

There was discussion of whether or not it was always better to fit a stock recruit model or if you should only do so if you tested for statistical difference from the null hypotheses. It was concluded that models may be fitted, but one would want to make sure they do better than straight line (or average where all your data are in the asymptote).

It is known that these methods have potential biases. For example, BH50 limit could be lower than it should be if your data are from the lower part of the curve. Uncertainties also exist that are magnified if you are using the limit as a target for recovery. Therefore, it may be better not to manage by reference point and risk, but rather to use a simple feedback harvest control rule where the LRP is a performance statistic.

It was also mentioned that PA working group discussions determined that all methods have potential biases. In this, the DFO framework has not kept up to international debate and state of knowledge. Therefore, managing by reference points and risk may not be as helpful as it could be, putting DFO years behind in state of knowledge and practice. Other papers, e.g. Butterworth; Hilborn, that suggest other approaches.

METHODOLOGIES FOR SETTING LIMIT REFERECE POINTS IN ATLANTIC HALIBUT AND HADDOCK

Presentation by Bob Mohn

Summary

BRP examples from Atlantic halibut, 4X haddock and 4VsW were presented. The halibut presentation emphasized manners to estimate and display uncertainty. The HCR was based on FMSY and 40 and 80 % SSB MSY determined from a Sissenwine-Shepherd analysis

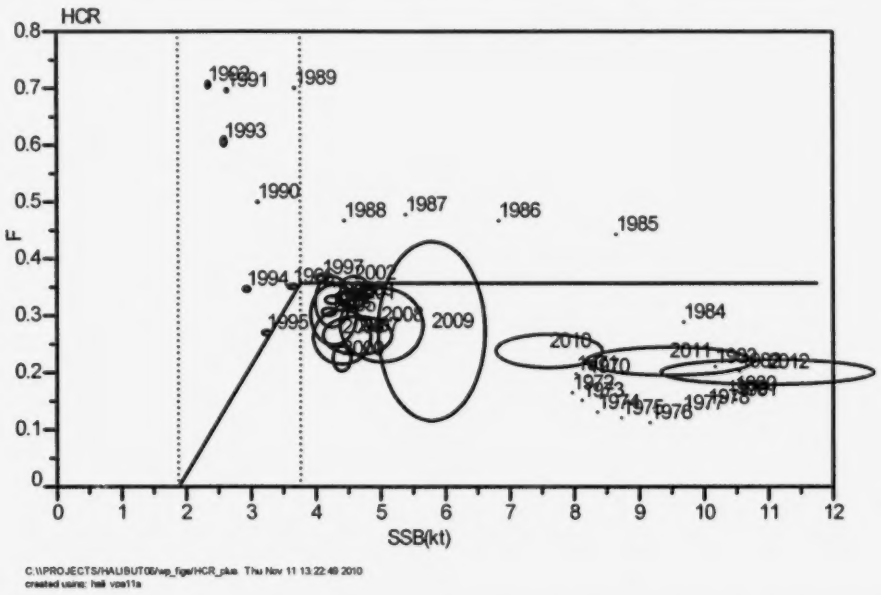


Figure 5. Harvest Control Rule (Fishing mortality (F))and SSB for Atlantic halibut. The (black) ellipses represent the uncertainty in the stock while the red ellipse are projections for 2010-12

The data were fit to a VPA and the (black) ellipses represent the uncertainty in the stock while the red ellipse are projections for 2010-12. These ellipse are from (conditioned) bootstrapping of the residuals from the two surveys at age used to tune this model. Uncertainty in the SSBMSY and FMSY was again based on a bootstrap analysis in which the residuals for a Ricker fit stock-recruit data and M with a 20% coefficient of variation. The HCR now has a certainty width, the red line is one s.d. the orange line is two.

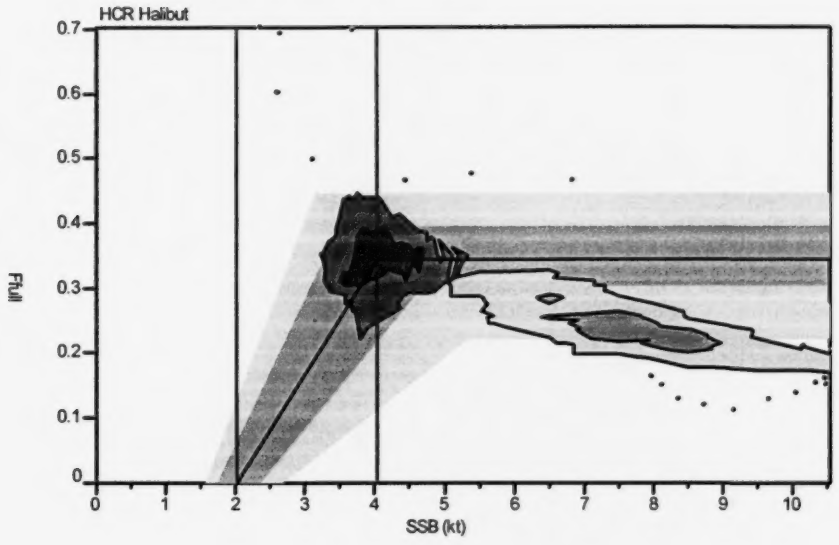


Figure 6. Harvest Control Rule (Fishing mortality (F)) and SSB for Atlantic halibut. The uncertainty in the stock and projection (grey scale) are represented by contours.

If the uncertainty in the 2010 projection is displayed as contour of probability distribution instead of the ellipses in the previous figure. The probability of this cloud exceeding the "soft" limits can be estimated with numerical integration.

The 4X haddock was presented as it is a stock which has undergone a rapid and so far un-reversed change in growth about 1986. The long term Sissenwine-Shepherd analysis estimates MSY and SSBMSY at about 14 and 44 kt respectively.

The resultant HCR and stock trajectory are again shown with error ellipses and a three year projection in red.

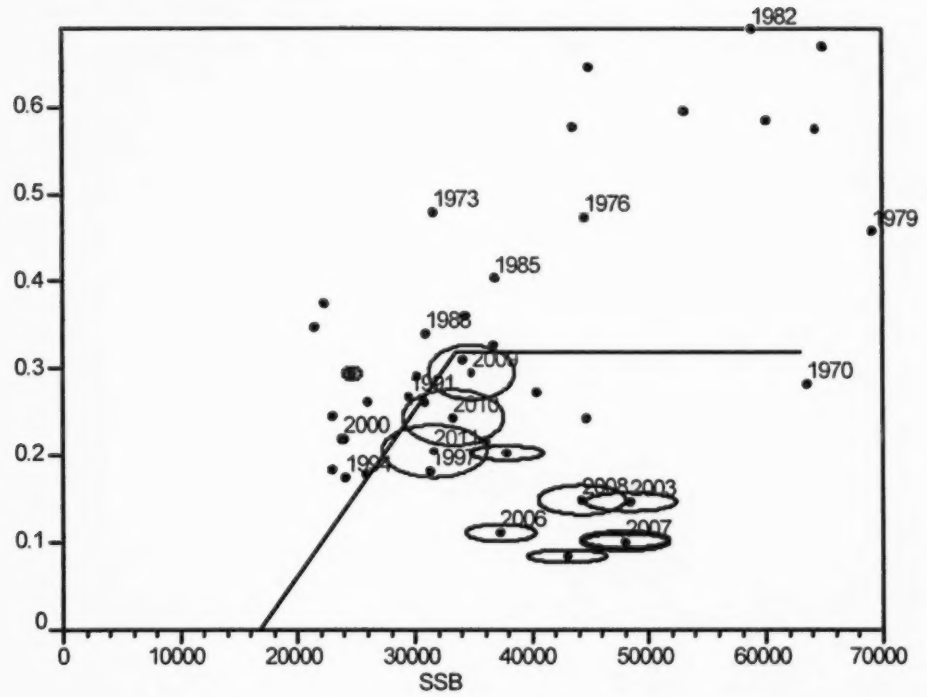


Figure 7. Harvest Control Rule (Fishing mortality (F)) and SSB for 4X haddock. The (black) ellipses represent the uncertainty in the stock while the red ellipses are projections for 2010-12.

However, if this analysis is performed on moving windows of data, the affects of the change in growth are clearly seen. The upper black lines are BMSY for the windowed and total data series while the lower red lines are MSY.

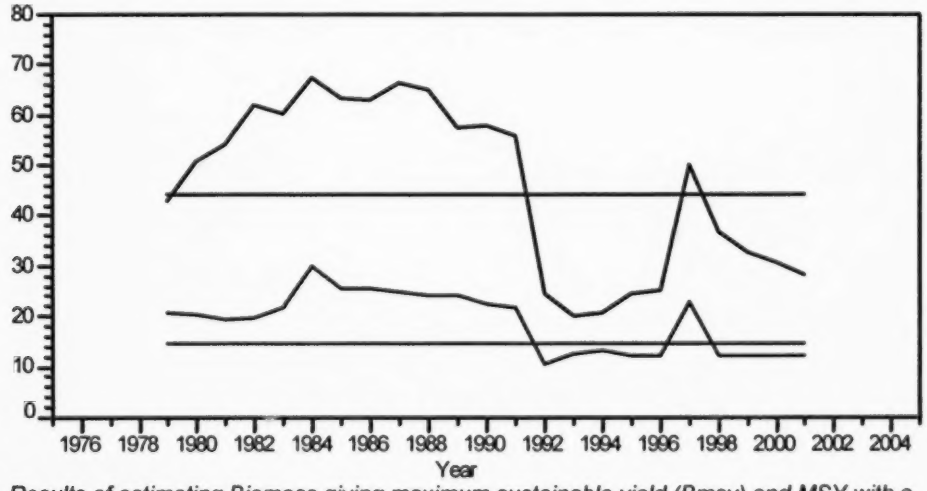
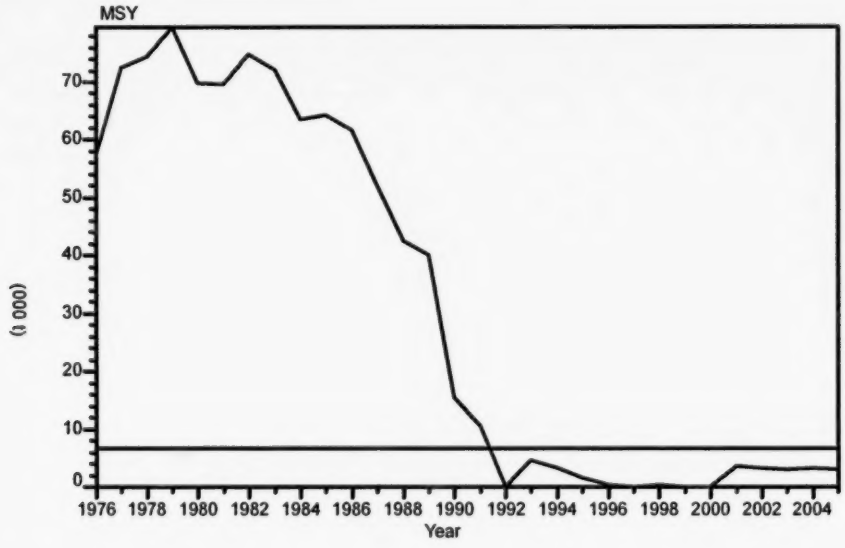


Figure 8. Results of estimating Biomass giving maximum sustainable yield (Bmsy) and MSY with a moving window analyses.

The upper black lines are BMSY for the windowed and total data series while the lower red lines are MSY

In terms of MSY, the early years (before1991) show that they are consistently above the long term average, say averaging 20 kt compared to the 14 kt long term estimate. Haddock, since the early 1990s, is in a less productive period (due to depressed growth) with no sign of return to earlier rates. Nor is there indication that reduced fishing would switch growth back to earlier levels. Reproduction and survivorship are not impaired and thus no indication of "serious harm" and reference points based on the new regime could be considered. As this stock represents a somewhat unusual case, more analysis is required.

In contrast to haddock, 4VsW cod has experienced a dramatic change in natural mortality while growth has been relatively stable. When a production analysis is undertaken using results from a VPA with random walk M's, MSY and BMSY are seen to be sensitive to this parameter. This change in mortality has taken equilibrium surplus production (MSY) from about 60 kt in the 1970s to essentially zero in recent years.



From: ssprodtuna_08
C:/PROJECTS/COD4VSW/COD_RAP11/4VsW_msy Mon Nov 22 09:54:20 2010

Figure 9. Maximum Sustainable Yield (MSY) for 4VsW cod calculated using a moving window.

The MSY based on long term average inputs is less that 8 kt. Similarly, the BMSY went from about 200 kt in the 1970's to less that 20 kt in recent years with 44 kt for the entire data set.

A comparison for these three stocks of the 40% SSBMSY and stock-recruit based LRPs is of interest. For halibut the MSY based point was 2 kt and the Bmin was 2.36. Similarly, for haddock the long term MSY LRP was 17 kt while Bmin was 21. In both these cases PA points from stock-recruit data tended to be lower than either Bmin or .4 BMSY. Because of the magnitude of the change in productivity, 4VsW cod presents a more difficult case.

LRP (kt)	.4 SSB MSY	SSBmin	Rk50	Bh50
Halibut	2	2.4	1.1	0.1
Haddock	17	21	11.4	5.5
4VsW cod	72,17,~0*	10.5	26	24

*these three are for the productive period, long term average and unproductive periods

The long term average is steadily decreasing as more years are added from the non-productive period while the stock is slowly growing. If these trends continue, the stock will cross an MSY-based LRP. However, there is very little production from the stock and an LRP more heavily based on the on the productive period seems preferable.

Recruitment describes only part of the productivity of the stock and other factors (growth, maturity, fecundity, mortality) are also important. All aspects of productivity need to be considered when determining removal rates. However they may not all be needed to define regions of "serious harm". For example, if a domain of biomasses were identified that showed compromised recruitment, that alone could, and should, be used to define a LRP. The comparison of MSY-based and recruitment-based LRPs for these three stocks showed roughly commenserate references.

The use of long term mean production in the definition of (MSY-based) LRPs is only appropriate when the production has a stable, although variable, production. That is that the mean is describing some sort of stock attribute that persists in time and may be expected to persist into the future. For both haddock and cod, rather clear periods of good and bad productivity have occurred. For cod the long term does not seem sufficiently conservative. For haddock it may be too conservative.

Uncertainties were presented for both the stock status (past and projected) and the MSY-based BRPs. They were based on bootstrapping and this or similar analysis should accompany advice of BRP's and stock status, especially if there was a need for risk analysis.

Discussion

It was noted from the presentation that there is the possibility of a regime shift – to a smaller but productive stock which can still be fished. If there is a regime shift and you still have a productive stock to fish under a low regime fishery. However, this depends on the circumstances, e.g. biomass has declined but abundance has remained high.

The Chair noted that additional data (for example, a large recruitment event) would require a review of the LRP – although this would need to be considered on a case by case basis.

For haddock, a change in growth that persisted for a long time would result in different LRP's. But what is the conclusion for cod? It appears that looking at the whole time series, the LRP for cod would be high. However, looking at it now, the LRP is much lower. Therefore, there is the need to be aware of the present biological reality as well as the long term picture.

It was suggest that it would be more useful to have a target that is perhaps based on average B_{msy} in time and fish low enough to get at the target.

For halibut, it was noted that stock/recruit is only one part of production.

For haddock, growth has been much lower for approximately 30 years. Therefore, if time trends are included in the analyses the MSY and Bmsy would be much lower in recent years.

The examples show many changes over time, but according to framework one would use long term average. In questioning why the long term average would be used if things had changed, i.e., how would one know if it will go back or not, it was noted that given the policy you would have to experiment for letting it go back.

There was a suggestion that the mean incorporates good or bad, but whichever is used needs to be reevaluated as more data is gathered.

It was concluded that whether or not you 'invoke regime shift' and change the LRP will depend on your concern for the stock. For example, if numbers are really low one probably wouldn't want to do this because there is a risk of not going back to a previous regime.

There was no clear consensus on whether or not different LRP should be set as productivity differs. It is clear that there are differences in productivity over time. However there are also uncertainties about productivity levels and the LRPs.

It was questioned whether or not a different LRP should be suggested for this cod stock now? Maybe a target based on something you could get back to in a few generations should be identified.

LIMIT REFERENCE POINTS IN OTHER COD STOCKS

3Pn4RS Summary

Presented by Daniel Duplisea

Eight methods were applied to S/R data. Only 2 peer reviewed models were found to give a good fit to the data and not have been shown to have poor properties as a method for setting LRP. The average of these 2 S/R models was used as the basis of setting the LRP of 116,000 t of SSB.

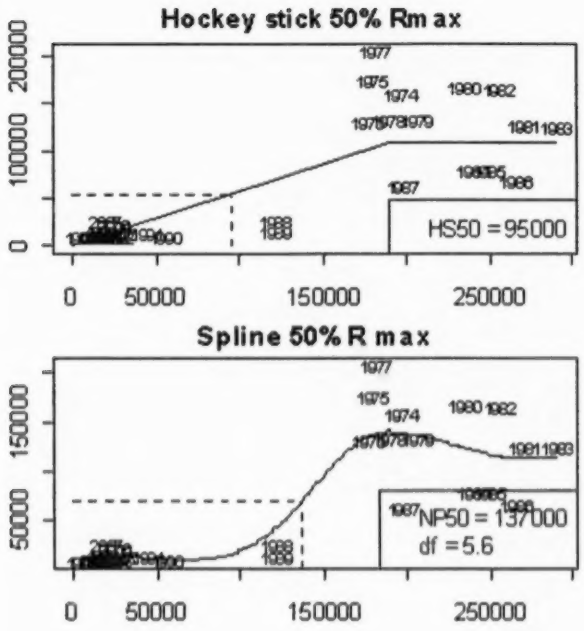


Figure 10. Hockey stick (top) and non parametric spline (bottom) fit to stock and recruit data for 3Pn4RS cod.

4T Summary

Presented by Doug Swain and Joanne Morgan

Five methods were applied to the data all giving a LRP in the range of 70 – 80 000 t. There were 4 methods based on stock recruit data. These were the SSB giving 50% max R from 3 S/R models (Beverton-Holt, Ricker and Loess) and SSB 50/90 (the Serebryakov method). In addition $B_{recover}$ was determined. It was concluded that the best estimate for this stock was 80 000 t. This will be reviewed in December 2010.

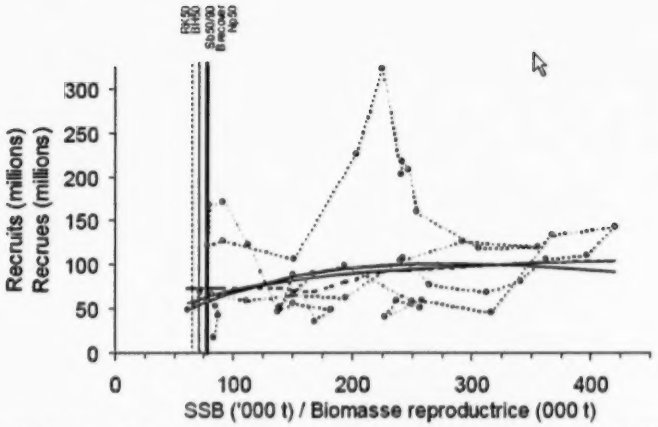


Figure 11. Several stock recruit models fit to stock recruit data for 4T cod. The LRP as determined from several different methods are indicated by straight vertical lines.

3Ps Summary

Presented by Brian Healey

A limit reference point for the 3Ps cod stock was established during the 2004 regional assessment. There was wide variation in the point of impaired recruitment as inferred from B50 (the biomass at 50% of Rmax). Estimates of B50 were determined from stock-recruit models applied to one of the several VPA models in use at that time. Considering these difficulties, B50 estimates were not accepted as potential LRPs. However, Brecovery (lowest observed stock size from which there has been a recovery) was accepted as SSB limit reference point for 3Ps cod, this corresponded to the 1994 SSB level. Subsequent to this, management advice has related current SSB to the LRP when model estimates of SSB have been available.

3NO Summary

Presented by Don Power

The B_{lim} for Div. 3NO cod was established by NAFO Scientific Council in 1999 from a VPA that estimated Population Number to Jan 1, 1999. Age 3 recruits were plotted against spawner biomass derived from an ADAPT calibrated using Campelen converted Spring & Autumn RV series + Juvenile flatfish RV series. This provided a S/R series from 1959-1996.

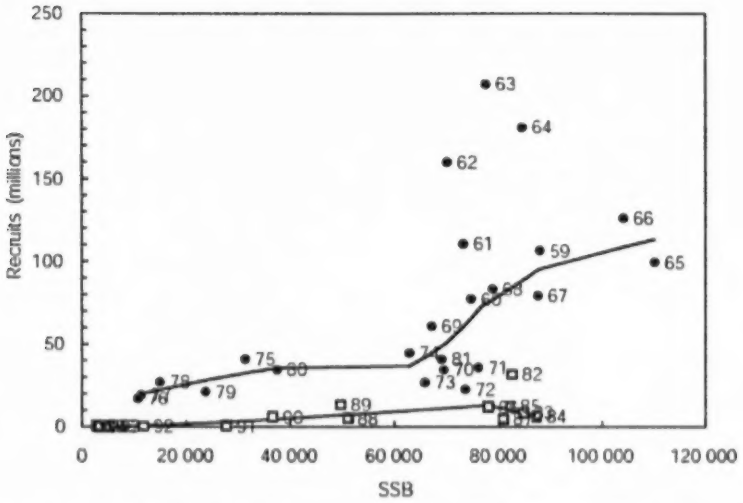


Figure 12. Stock and recruit data for 3NO cod. The numbers indicate the year class. Two Lowess smoothers are fit to the data. One including data to 1981 and the other data from 1981 to 1994.

The SSB and recruitment data over the 1959-96 period indicate a sharp decrease in the likelihood of obtaining high recruitment at SSBs below 60 000 tons. The Scientific Council therefore considers that 60 000 tons is the current best estimate of Blim. There is an indication of even further reduction in recruitment at about half the Blim level. Scientific Council will review in detail the biological reference points in the context of the PA framework when the SSB has reached half the current estimate of Blim.

LIMIT REFERNCE POINT FOR 2J3KL (NORTHERN) COD

HISTORICAL PERSPECTIVE ON MSY-BASED REFERENCE POINTS

Presented by Peter Shelton

There has been a long history of historical catches on the 2J3KL cod stock with peak catches estimated to have been as high as 800,000 t in the 1960s. The last accepted VPA-based assessment of the stock was conducted in 1992. This assessment indicated that SSB and recruitment in the 1960s were substantially higher than those that occurred with the survey time series (1983+). The last period over which reasonable recruitment occurred was 1983-89 and the average spawner biomass over this period provided a candidate Blim (LRP) for the stock.

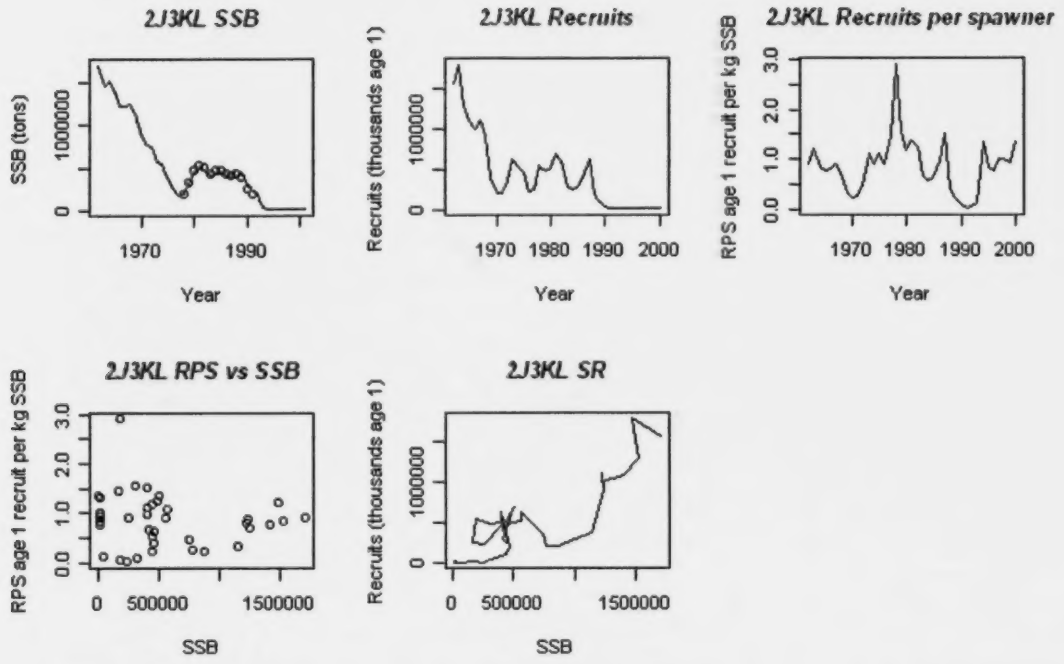


Figure 13. Historic view of 2J3KL cod based on the 1992 assessment (Baird et al. 1992) (circles) and the "missing cod model (Shelton and Lilly, 2000; Shelton et al., 2006) (line). Top left – estimates of historic SSB; top center – historic recruitment levels from the missing cod model; top right – recruits per spawner; bottom left – recruits per spawner against SSB, bottom right – stock-recruit plot.

Discussion

It is clear that the population size of northern cod is much smaller now than it was in the past. It was concluded that to only use recent data in the setting of a LRP would not reflect this and would be inappropriate.

In 2003 a Blim of 400 – 500K tonnes was derived. A milestone of 150 000 t of SSB was set and it was expected that the LRP would be above 300 000 t of SSB.

There was some discussion of stock structure. It seems clear that some components of the stock have been lost (e.g. the Virgin Rocks).

One possible approach to setting of an LRP is to examine the S/R data to see when good recruitment was estimated to have occurred. The 1980's was the last period when any reasonable recruitment was seen.

After the 1980's SSB for 2J+3KL has been lower and recruitment poor, indicating that the stock has been below a level where serious harm occurs. This stock is known to have episodic recruitment events and there were some low year classes in the 1980's. However, even these low recruitment episodes were well above subsequent recruitments.

Currently we do not have a VPA for this stock. There was some discussion of how to relate our current survey to the past VPA. One approach could be to take the VPA numbers from a previously accepted model and relate this to the Campelen survey in the same time period to get a q for Campelen.

The possibility of using Brecover as an LRP for this stock was discussed. The stock recovered from low population size in the late 1970's. However, this was the result of extraordinarily high recruits per spawner and so does not seem a good candidate for Brecover.

INDICES OF SPAWNING STOCK BIOMASS AND RECRUITMENT OF NORTHERN COD FROM SURVEY DATA

Presented by Brian Healey

Estimates of cohort strength were produced from indices of age 2-4 abundance from the fall survey time-series (1983-2009). Linking these to the estimates of spawning biomass from the survey, estimates of B_{50} were determined from Beverton-Holt and Hockey-Stick SR models. These estimates were considerably different one another owing to the patterns in the SR data. It is, however, clear that recent SSB and recruitment are presently much lower than those estimated from the 1983-1990s.

The main intent of this work was to provide a comparative series to the estimated survey recruitment and spawning biomass as inferred from SURBA.
Brian Healey presentation

Survey Stock-Recruit Data

Beverton-Holt model puts LRP at sightly less than 400K tonnes. "Hockey Stick" model would put it at about 9K. Obviously, there are problems with both.

In the early 1960's, there were fish caught in the 15-20 year classes. Since 1992, there are few older than about age seven. We are looking at a vastly different stock today relative to the earlier decades.

The conclusion is that very different SR fits are derived from the different models. Consequently, there is a broad range of northern cod LRPs generated from the models. It cannot be determined which model provides more appropriate advice since both models are dependant on assumptions and there is no way to confidently evaluate the validity of the assumptions. It is therefore impossible to determine which is more appropriate in terms of advice.

SURVEY MODEL (SURBA+) FOR 2J3KL COD

Presented by Noel Cadigan

The northern cod stock was, and still is, comprised of various components, most of which are greatly diminished in size. There are small components that reside in the inshore all year but historically the vast majority of the stock over-wintered in the offshore. A limit reference point (LRP) for the entire northern cod stock is essentially the same as the LRP for the offshore component. Only limited information exists on the size of the inshore components. The offshore

components have been survey annually in the autumn research vessel (RV) survey and can be used to establish an LRP for the stock as a whole.

In the 2010 assessment of 2J3KL cod, a cohort analysis of autumn RV catch rates was used for the first time to infer trends in the status of cod in the offshore. The basic model (SURBA) is described by Cadigan (2010), and details of the 2J3KL cod application are given in Brattey et al. (2010). The model was applied to RV data from 1995-2009 and ages 2-8 to infer trends in recent total mortality rates (Z's) and recruitment rates. The model was not applied to ages greater than 8 because of the recent very low catch rates at these ages, and the model was not applied to survey data prior to 1995 because of problems with the model fit. The separable Z assumption did not seem appropriate over the entire survey time period.

The 2010 assessment model formulation was insufficient for LRP determination because the short time frame of the model did not cover the 1980's when stock size and recruitment was much higher. Also, the limited age range in the 2010 SURBA model would produce partial and therefore biased estimates of SSB if the model was extended to the 1980's. Including more ages and years was considered necessary for LRP analyses.

In preliminary analyses, the basic SURBA model with a separable total mortality assumption (i.e. $Z_{ay} = f_y s_a$) was applied to the RV index for 1983-2009 (excluding 2004 because of missing strata) and ages 2-12. Any indices with values of zero were given zero-weight in the parameter estimation. Age 1 was not included because survey catches prior to 1995 are not comparable to catches since then because of the change in the survey trawl (i.e. Campelen). Ages 2-12 were used because survey SSB at ages greater than 12 was a small fraction of total SSB, ranging from 1.25-3.5% during 1983-91. The model formulation was otherwise similar to that described in Brattey et al. (2010), except that the survey catchabilities (q's) that are input values to SURBA (see Cadigan, 2010) were assumed to have an asymptote of one (Figure 14) so that the scale of SURBA abundance and biomass estimates is the same as the survey scales (i.e. mean number per tow, and Kg per tow, respectively). Ages 4-12 are assumed to be equally selected by the survey. The pattern in q's was otherwise similar to that used in Brattey et al. (2010).

Similar to the findings in Brattey et al. (2010), this model resulted in a poor fit with gross patterns in residuals (see Figure 15). Such residual patterns suggest that the model does not well describe the patterns in the RV indices, and also suggests that the model provides a poor description of population trends and Z's. The basic problem is that the age pattern in Z's has not been constant over time, as assumed by the model. This pattern was computed directly from the survey indices ($Z_{ay} = log(I_{ay} / I_{a-1,y-1})$) and, although noisy (Figure 16), suggests that the pattern has changed over time. The pattern in the bubble plot in Figure 16 is broadly similar to the residual pattern in Figure 15. Note that the Z's for younger ages were computed by dividing the survey indices by the q's in Figure 14.

The SURBA model was extended to allow some variation in the Z age-pattern over time. This extension is referred to as the SURBA+ model.

SURBA+ for 2J3KL cod

The SURBA model was extended by treating $Z_{a,y}$'s as random effects that change smoothly over time. For the first age in the model (i.e. model age 1; actual age 2), let

	$\delta_{1y} = \log(Z_{1y})$ and $\delta_{1y} = \delta_{1y-1} + \varepsilon_{1y}$, $y = 2,...,Y$,	(1)

where the ε_{1y}'s are independent and identically distributed (iid) normal random variables with zero mean and variance $\sigma^2_{1\varepsilon}$, which defines a simple random walk for $log(Z_{1y})$. In Equation (1), the log differences in Z's are assumed to be random, and should differ only if the data suggest the differences are significant. The size of the differences is controlled by $\sigma^2_{1\varepsilon}$, whose estimation is described later in this Section.

The $Z_{a,y}$'s for other ages were also treated as random walks, but correlated so that the age patterns in Z's varied more smoothly over time. There are several ways to achieve this. The strategy selected was

$$\log(Z_{ay}) = \log(Z_{a-1,y}) + \delta_{ay},\ a = 2,...,A,\ \text{and}\ \delta_{ay} = \delta_{a,y-1} + \varepsilon_{ay},\ y = 2,...,Y, \quad (2)$$

where ε_{1y}'s are iid $N(0,\sigma^2_{1\varepsilon})$. Equation (2) suggests the Z's should not be too different for adjacent ages, and that the differences should only vary from year to year if the data suggest the differences are significant.

The random walks in Equations (1) and (2) require some starting conditions. The random walks were actually started twice, in the first year and also in 1994 to accommodate the potentially abrupt change in mortality pattern, as indicated by the separable residuals (Figure 2). In the first year (model year 1) and in 1994 (model year 12) the δ's were modeled as cubic polynomial functions of age, *s(a)*,

$$\delta_{ak} = s_k(a) + \varepsilon_{ak},\ a = 1,...,A;\ k = 1\ or\ 12 \quad (3)$$

where ε_{ay}'s are iid $N(0,\sigma^2_{a\varepsilon})$. The cubic polynomials are used to roughly set the mean levels for the δ's, and fine tune adjustments are made by the ε_{ay}'s.

A random walk means that there is auto-correlation in Z's, and the amount of autocorrelation changes with time. The difference between $Z_{a,y}$ and $Z_{a,y-1}$ depends on $\sigma^2_{a\varepsilon}$ which may differ by age. $\sigma^2_{a\varepsilon}$ was constrained to be equal for ages 2-3 (young), 4-8 (medium), and ages 9-12 (old). Hence, only three of these variance parameters are estimated.

There are a large number of effects (parameters and random terms) to estimate in this model. There are *A* initial numbers at age (N_{a1}'s), *Y-1* other recruitments (N_{1y}'s), 8 parameters in the 2 cubic polynomials ($s_1(a)$ and $s_{12}(a)$, Equation 3), the *AxY* ε random effects in $Z_{a,y}$'s (Equations 1-3), and the three variance parameters $\sigma^2_{young,\varepsilon}, \sigma^2_{medium,\varepsilon}$ and $\sigma^2_{old,\varepsilon}$. However, the random effects are not all freely estimated. AD Model Builder (ADMB Project 2009) and the random effects module was used to implement the model. Fixed effects parameters, denoted collectively as the parameter vector θ, are estimated via maximum likelihood (MLE) based on the marginal likelihood, $L(\theta)$, in which random effects are "integrated out". Let Ψ denote the *AxY* matrix of random walk error terms ε_{ay}'s. The marginal likelihood is

$$L(\theta) = \int\int_{\Psi} f_\theta(I_{11},...,I_{AY} \mid \Psi) g_\theta(\Psi) \partial\Psi,$$

where $f_\theta(I_{11},...,I_{AY} \mid \Psi)$ is the joint probability distribution function (pdf) for the RV indices and $g_\theta(\Psi)$ is the joint pdf for the random effects (Ψ). This high dimensional integral is numerically evaluated using the Laplace approximation in ADMB. The MLE's of θ maximize $L(\theta)$. The random effects Ψ can be predicted by maximizing the joint likelihood, $f_\theta(I_{11},...,I_{AY} \mid \Psi)g_\theta(\Psi)$. Additional information on these procedures is provided by Skaug and Fournier (2006).

Treating high dimensional parameters as random effects is often a good approach to avoid over-fitting the data. Estimating other fixed effects parameters via marginal likelihood is usually better than penalty based approaches. In the random effects approach, the data decides the penalty, through the random effect variances.

SURBA+ Results

Treating *Z*'s as random walks resulted in much improved residuals (Figure 17) with no major patterns compared to the separable Z model (Figure 15). The age patterns in SURBA+ Z's (Figure 18) are smoother than for the direct survey results (Figure 16), as expected. The SURBA+ Z's were usually similar to the direct survey Z's (Figure 19). The survey Z at age *a* was inferred from the fall RV index compared to the index from the pervious year and age. Note that the age 2 survey Z's may not be reliable because they are based on RV catch rates at age 1 that have more uncertainty, particularly prior to 1995 when the Engels survey trawl was used.

Both raw and SURBA+ Z estimates suggest that mortality rates were at times very high. For example, the value of Z = 4.21 at age 8 in 1993 indicates that 99% of those fish died. The average trend (Figure 20) reached very high levels in the early 1990's and then rapidly declined in 1995. The Z's increased again until 2002, and then declined to low levels in 2004-08. The high average Z in 2009 is caused by high Z's estimated at ages 6-12 (Figure 19).

The SURBA+ predicted survey indices closely followed the observed survey indices (Figure 21). The largest discrepancies were for 1986, which is generally thought to be a year effect. No patterns in residuals were apparent (Figure 22).

SSB was derived from SURBA+ by projecting beginning of year numbers at age to mid-year by applying 50% of the estimated Z, and then multiplying by survey weights at age and maturities, and summing over ages. SSB was also derived directly from the survey. Both sets of results were adjusted up by the survey swept area. The survey estimates differed from the SURBA+ estimates (Figure 23), because the survey occurs in the fall and additional mortality occurs between then and mid-year when the SURBA+ SSB was computed. Mid-year SSB is thought to be a more reliable indicator of the true SSB.

SURBA+ recruitment estimates were compared to results from an analysis of year class strength at ages 2-4 (Figure 24). The two sets of estimates were broadly similar, although differences in the recent estimates were apparent.

Stock-Recruitment (SR)

Both the Beverton-Holt (BH) and hockey-stick (HS) stock-recruit (SR) models were fit to the SURBA+ estimates of recruitment at age 2 and parental mid-year SSB (Figure 25). Both models fit the data poorly, with patterns in the residuals. For example, both models provide a poor fit to the estimated recruit per spawner relationship with SSB (Figure 26). They could not match the decline in recruitment rates at low stock sizes.

An interpretation of these results is that recruitment is a more complicated function of SSB than the BH or HS models. Alternatively, the SR relationship may have changed over time. The first interpretation is considered to be more relevant because it seems plausible that the historic recruitment levels of the 1980's could be attainable again if SSB also increased to the levels of the 1980's. Fitting two SR models to the pre and moratorium periods may also fit the data better, but the fit to the moratorium period data would imply low recruitment levels even if the stock SSB increased to the level of the 1980's, which seems an overly pessimistic view.

A more complicated SR model that is a mixture of two BH (base) models was used to better fit the SURBA+ SR estimates. Let $R_1(S)$ and $R_2(S)$ denote the two base SR models. The mixed-BH model is

$$R(S) = R_1(S)p(S) + R_2(S)\{1 - p(S)\}. \quad (4)$$

where the mixing proportion is a simple logistic function of SSB,

$$p(S) = \frac{\exp\{\lambda(S-\delta)\}}{1+\exp\{\lambda(S-\delta)\}}.$$

δ is the SSB "change-point" in the SR model and λ gives the size of the transition. This model implies a change in the SR dynamics as a function of SSB and not time which is an important point. The mixed-BH recruitment dynamics is assumed to be time-invariant. λ could be estimated, but for simplicity it was fixed so that the quartile range of the mixture was 200 Kt; that is, if $p(S_\alpha) = \alpha$ then $S_{0.75} - S_{0.25} = 200$. One can show that this constraint implies $\lambda = log(9)/200$.

The mixed-BH SR model fit the SURBA+ estimates much better (Figures 27 and 28), although there is some evidence of temporal correlation in residuals (Figure 28). This model suggests relatively low recruitment until the stock reaches approximately 400 Kt of survey SSB, after which recruitment is predicted to increase at a higher rate as SSB increases. Note that the CV reported for S50% (i.e. CV=0.4) was assigned and not computed. This CV was not used in any analyses, but could be computed in the future.

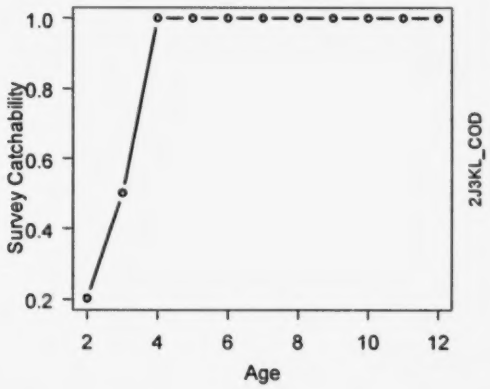


Figure 14. SURBA catchability (q) versus age

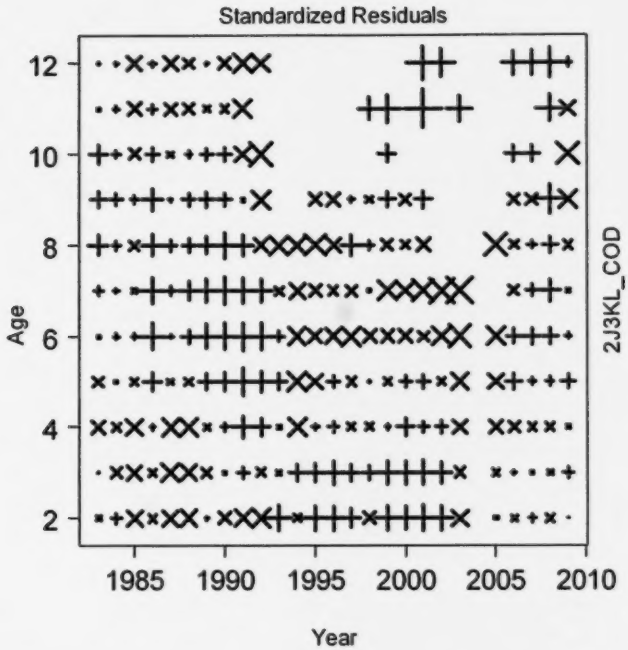


Figure 15. Matrix plot of residuals from the separable Z model. Red +'s are positive and black ×'s are negative. The sizes of plotting are proportional to the absolute value of the residuals. Blanks indicate values with zero estimation weights.

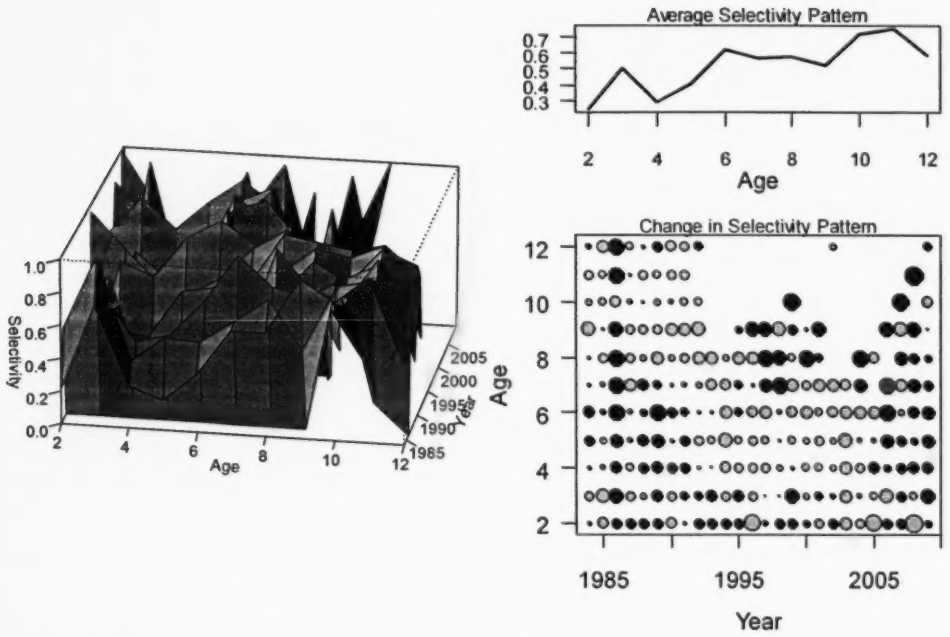


Figure 16. Left panel: Three dimensional graph of the age pattern in survey Z's (called selectivity), scaled to a maximum of one each year. Top right panel: Average selectivity at age over all years. Bottom right panel: Selectivity deviations from the average. Black indicates negative (i.e. less than average) and grey indicates positive.

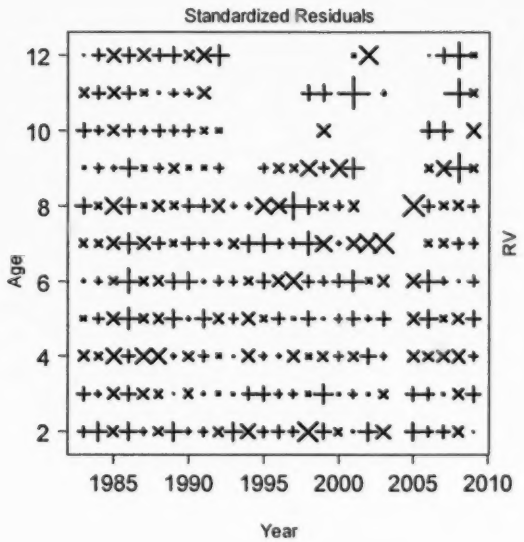


Figure 17. Matrix plot of residuals from the random walk Z model. Red +'s are positive and black ×'s are negative. The sizes of plotting are proportional to the absolute value of the residuals. Blanks indicate values with zero estimation weights.

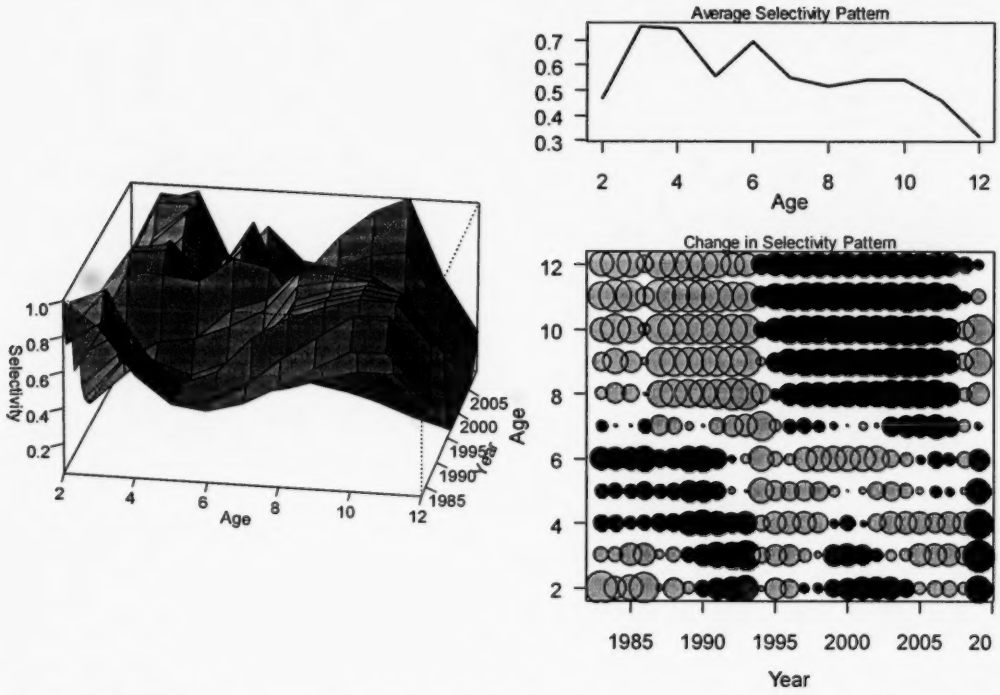


Figure 18. Left panel: Three dimensional graph of the age pattern in SURBA+ Z's (called selectivity), scaled to a maximum of one each year. Top right panel: Average selectivity at age over all years. Bottom right panel: Selectivity deviations from the average. Black indicates negative (i.e. less than average) and grey indicates positive.

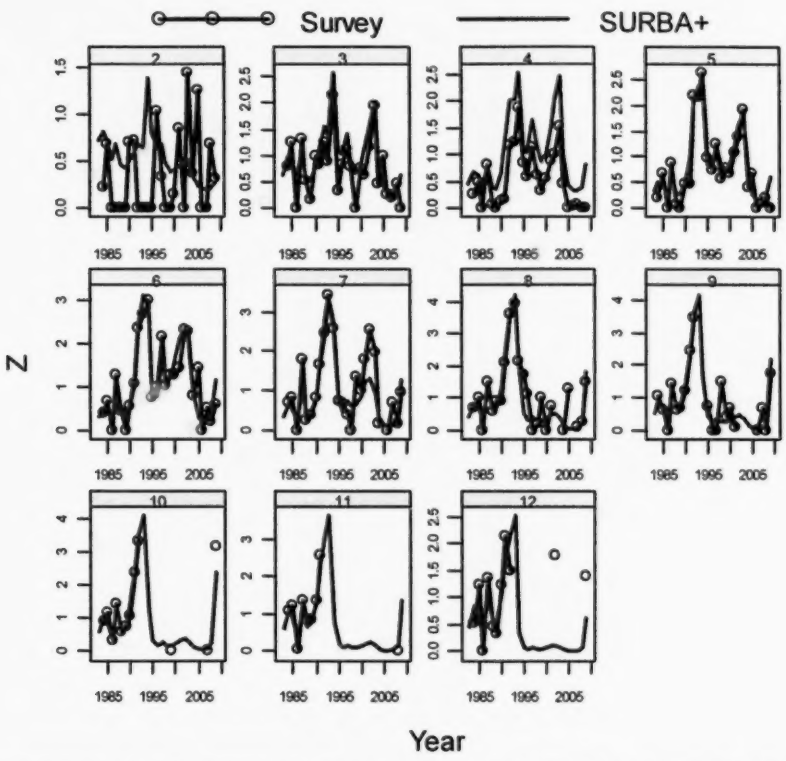


Figure 19. Raw survey Z's (points connected by black lines) versus SURBA+ estimated Z's.

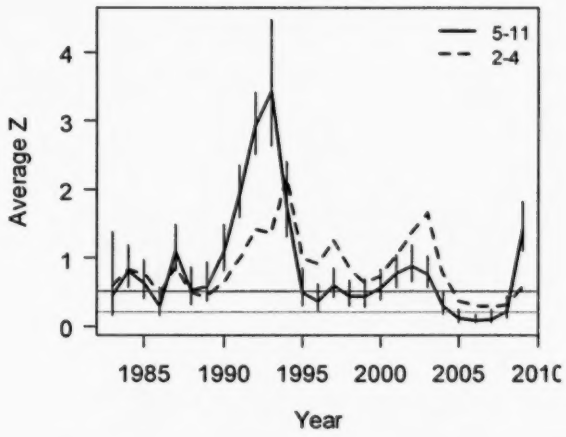


Figure 20. SURBA+ estimated Z's, average for two groups of ages indicated in the top right-hand corner. Vertical line segments indicate 95% confidence intervals. Reference lines at Z=0.5 (red) and Z=0.2 (green) are shown.

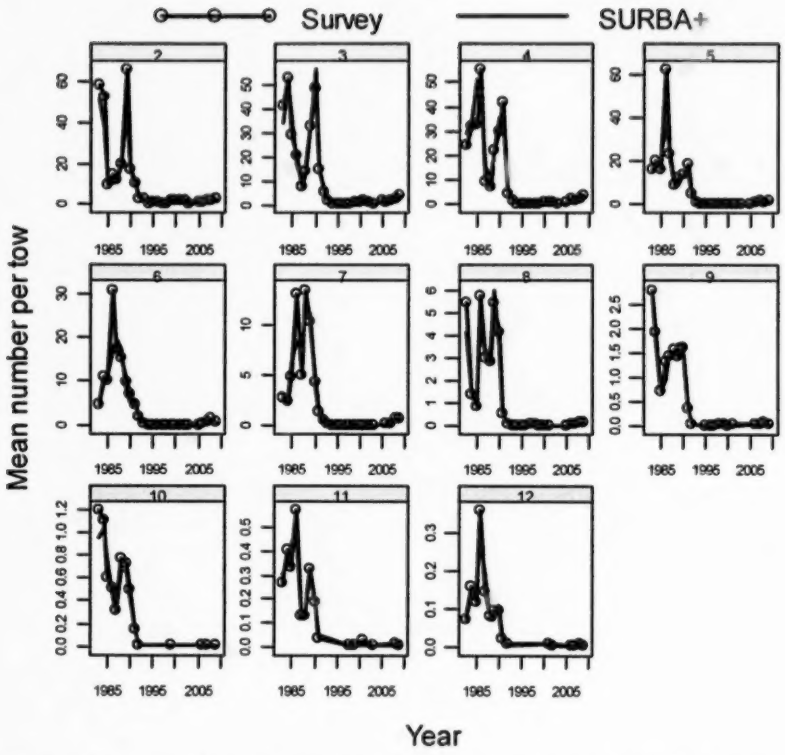


Figure 21. Raw survey indices (points connected by black lines) versus SURBA+ predicted values.

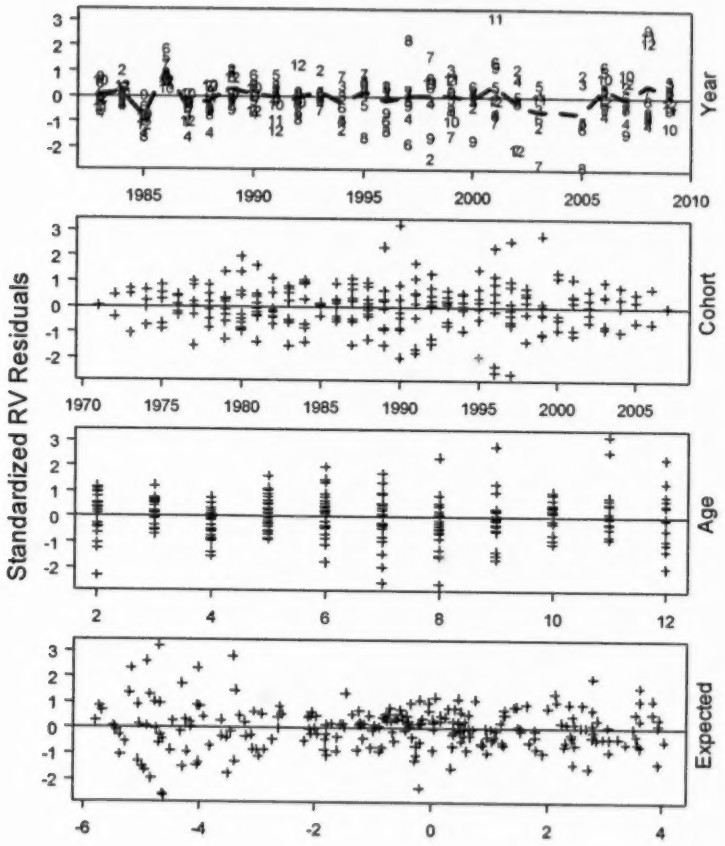


Figure 22. Standard residuals versus year, age, cohort, and predicted value. The dashed line in the top panel indicates the average residual each year, where the plotting symbols indicate age.

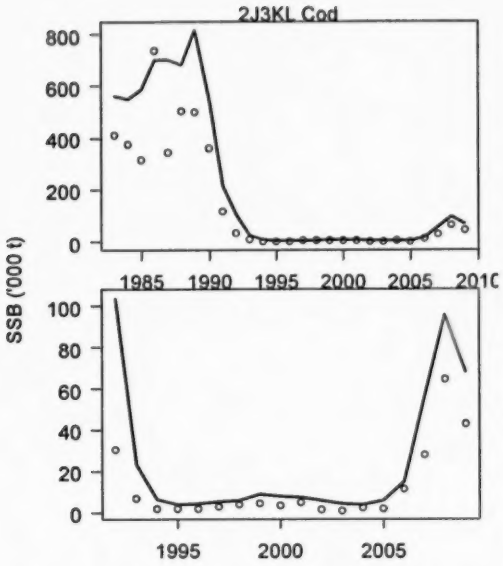


Figure 23. Raw survey estimates of SSB (points) versus SURBA+ estimates (lines). The top panel shows the results for the entire time-series, and the bottom panel gives results since 1992.

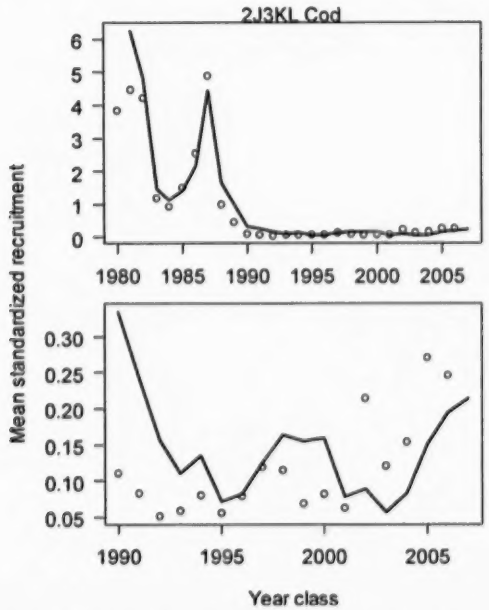


Figure 24. Estimates of recruitment (points) derived from a year class strength analysis, versus SURBA+ estimates (lines). The top panel shows the results for the entire time-series, and the bottom panel gives results since 1992. Both sets of estimates are standardized to the mean of their series, for comparison purposes.

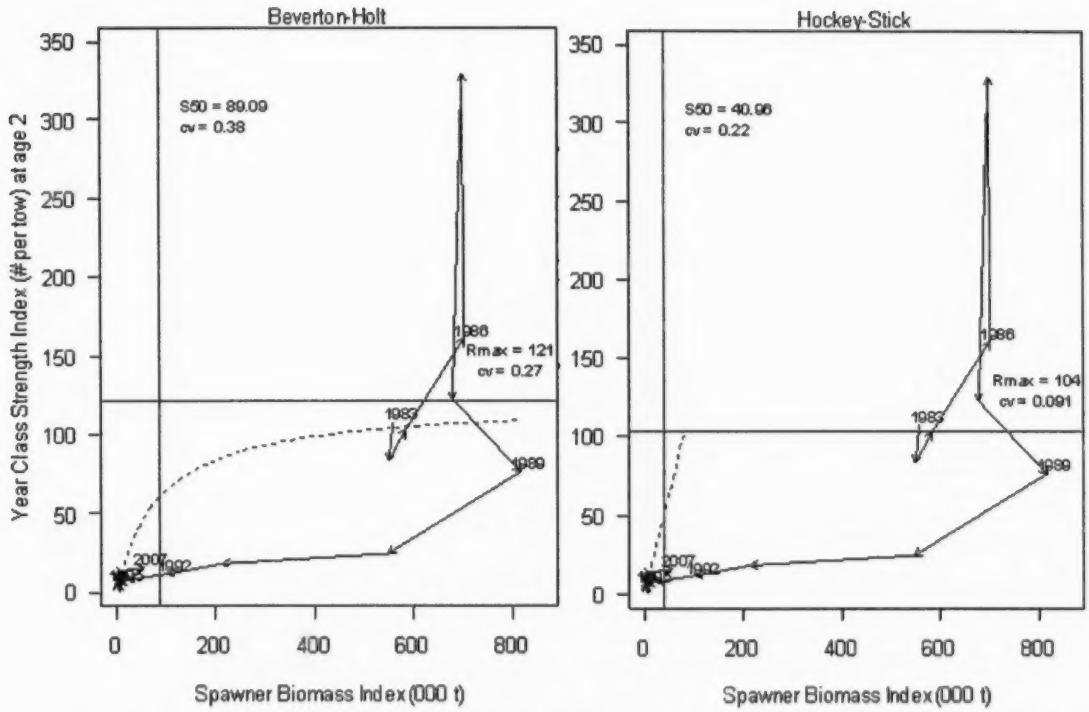


Figure 25. Beverton-Holt (left panel) and hockey-stick (right panel) models (dashed lines) fitted to the SURBA+ stock-recruit estimates. An arrow is plotted at each point, and indicates the time-series direction of the data. Some years are indicated. The red horizontal lines indicate Rmax, whose estimate and CV are shown at the right-hand side of each panel. The red vertical lines indicate the stock size corresponding to 50% of Rmax (i.e. S50), whose estimate and CV are shown at the top of each panel.

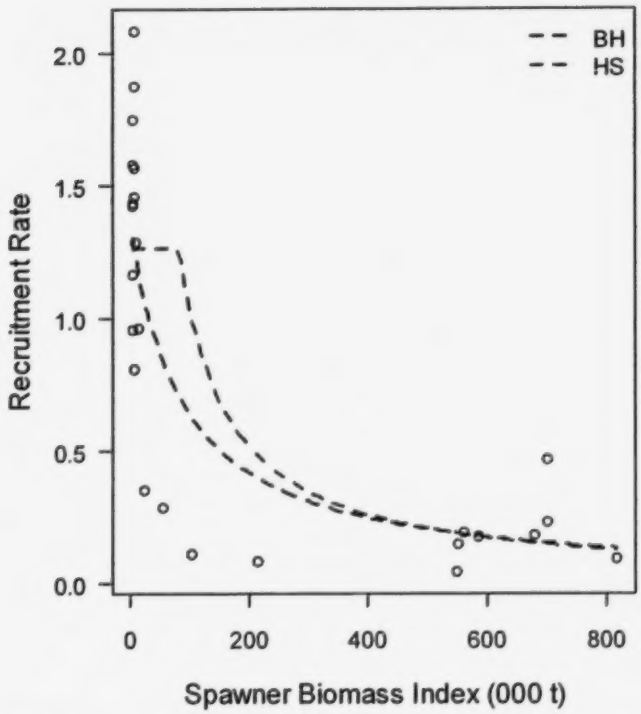


Figure 26. Beverton-Holt (black dashed line) and hockey-stick (red dashed line) estimates of the recruit per spawner relationship. SURBA+ estimates are shown as points.

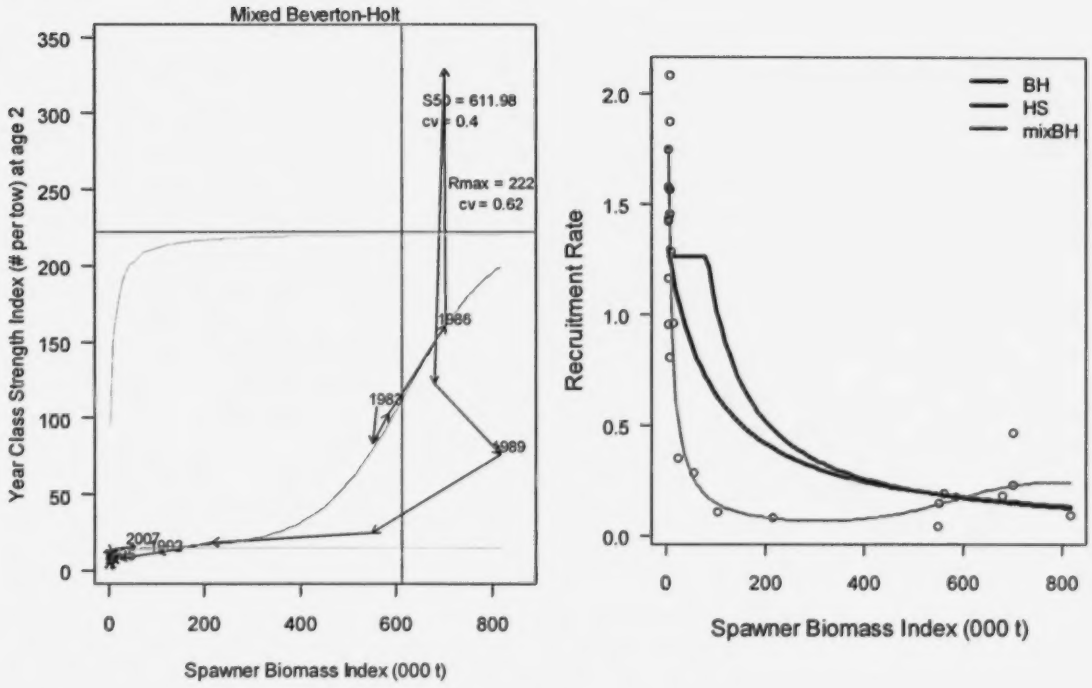


Figure 27. Left Panel: Mixed Beverton-Holt model (green line) fitted to the SURBA+ stock-recruit estimates. An arrow is plotted at each point, and indicates the time-series direction of the data. Some years are indicated. The red horizontal lines indicates the mixed-BH Rmax, whose estimate and CV are shown at the right-hand side of each panel. The red vertical lines indicate the mixed-BH stock size corresponding to 50% of Rmax (i.e. S50), whose estimate and CV are shown at the top of each panel. The two BH basis functions for the mixed-BH model are shown as grey lines. Right panel: Beverton-Holt (black line), hockey-stick (red line), and mixed-BH (green line) estimates of the recruit per spawner relationship. SURBA+ estimates are shown as points.

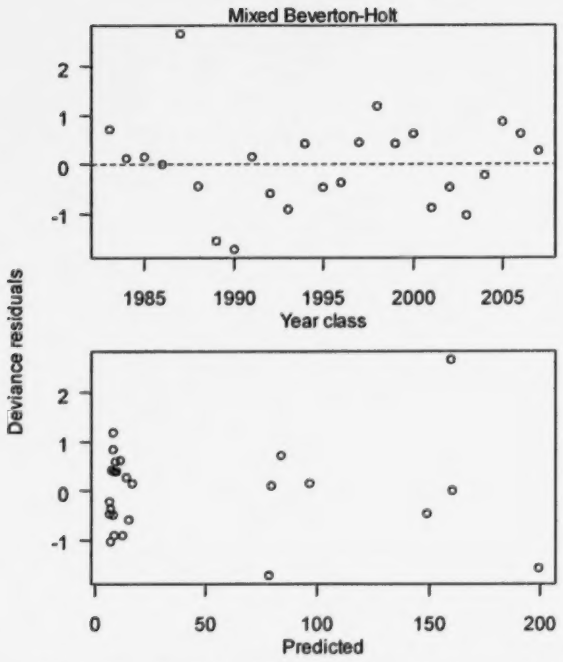


Figure 28. Stock-recruit residuals from the mixed-BH model, versus year class (top panel) and predicted value (bottom panel).

Discussion

Some aspects of the performance of the model are not well-understood with the current input data. The SURBA model that was started with has odd residual patterns that cannot be explained. However, once the LRP is derived there should at least be a better idea of the uncertainty with the estimate.

Regardless, the model fit is "very poor" for Northern cod data. The question was posed if this is also true with SURBA+? SURBA and survey Z's track to some extent. In fact, we don't see the same "misses" in the Z's, which could be a scaling issue in the plots.

It was questioned whether to base the analysis on data starting with1983 or to go back further in time when recruitment was known to much higher. Notably, there was a large increase in the recruitment rate at about 1995. Was this a change in survey gear or real change in recruitment rate at lower stock size? It is recognized that there could be issues with conversion of data between survey trawls but also that there is not the ability to correct this.

Based on observed changes in the residual pattern of 1994/95 the meeting was presented with some recent analyses from comparative fishing to test the survey gear effect. The greatest effects were observed with gear changes and not vessel changes, where the Campellan gear caught many more small fish (as expected). Still, the question of comparing survey catches pre- and post-1995 is not clearly answered by this. Therefore, there may not be compelling enough evidence to say there is a difference that would require splitting the analysis.

It was noted that the age composition in the survey catches may be affecting how we interpret the time series (because of the switch in survey gears) and that this could have an impact on the LRP we derive. However, the current meeting process is not in a position to determine what those impacts might be.

It was suggested that there isn't a willingness to fit the model to all of the historic data (going back to 1963). Recruitment was much higher in the 1960's and would therefore drive the LRP much higher than it would be if the time series in the analysis was much later in the continuum. On the other hand, is there merit in putting a SR model to post 1983 data to derive a LRP? Possibly not since these data come largely from collapsed/collapsing stocks.

Neither Beverton-Holt or hockey stick models seem to fit the data overly well. It was noted that if providing advice based on S/R there needs to be some confidence in fitting the data. With the conclusion that the S/R models don't fit, a new S/R model was proposed. This new model, the 'Hail Mary SR plot', or Mixed Beverton-Holt, assumes that the Beverton-Holt changes in relation to SSB. This is a more parameterized model that fits the data 'better'. This supported the idea that If we are going to provide advice we need to have a good fit to data and be confidant that it is accurate; that it makes sense and is statistically sound.

It was the feeling at this point that all of the information was now on the table. Therefore, whichever of the next steps used, recent data or a longer series, there is a requirement for some comment on where we are now and where we have come from. There is significant uncertainty that must be communicated in this.

Additional comments were put forward by participants on several of the uncertainties, including the debate in as to the robustness of the overall data series; the validity of the historic data; and known issues with the catch data – including catches that may have been inflated to influence management decisions pre-TAC days. At the same time, how do stock components fit into this? There was a period when a large spawning group existed inshore. Therefore, there may be some SSB in inshore that is contributing to offshore recruitment that is not captured in the SSB. There was also a period when the offshore component was not assessed. In the SSR, fish were considered to be inshore of the RV survey area. This also introduces a potential bias. Potential impacts of spawning components may have an effect of the S/R plots and is a source of uncertainty.

It was a conclusion of the group that the bottom line is that 2J3KL used to be an enormous stock, while it is now a miniscule stock. The historic performance of this fishery supports this.

ECOSYSTEM CONSIDERATIONS FOR LIMIT REFERENCE POINTS AND PROJECTIONS: EXPLORING BOTTOM-UP AND TOP-DOWN DRIVERS OF NORTHERN COD

Presented by Mariano Koen-Alonso

Alejandro Buren, Mariano Koen-Alonso, and Garry Stenson

Seal predation is one of the more frequent hypothesis put forward to explain the lack of recovery of Northern cod (NAFO Divs. 2J3KL) after the collapse in the early 1990s. However, other hypotheses include reduced prey availability and/or food quality (e.g. lack of capelin), as well as fisheries catches and environmental effects. This presentation discusses the results from a modelling exercise designed to incorporate all these effects simultaneously.

In this study we developed a bioenergetic-allometric biomass dynamic model which incorporates seal predation, capelin availability, and fisheries catches as external drivers of Northern cod population dynamics. The model is fitted by maximum likelihood to the cod biomass fall survey index for the period 1985-2007, and different model configurations are compared using the Akaike Information Criterion corrected for sample size (AICc). In order to fully represent the high variability across estimates of cod consumed by harp seals, two different shapes for the trend in consumption were used. One assumes an average seal diet over time, and hence, the trend in consumption follows the seal population trajectory. The other one, estimated from a multinomial regression approach to diet analysis, has an increasing consumption over the study period. In addition, both consumption series were also allowed to scale up or down by fitting a scale parameter that multiplied them. All these alternative representations of seal consumption, plus the inclusion or removal of capelin and fisheries effects, were used to define the scenarios explored.

Overall, the best model to fit the data was one that included capelin and fisheries catches, but without seal consumption. Based on the differences in AICc between this model fit and the other scenarios, all alternative models could be dismissed from further consideration (all differences >10). Hence, the consumption of cod by harp seals does not appear to be a significant driver of Northern cod during the study period. Fisheries and availability of food, on the other hand, appear as significant drivers of the dynamics of this stock.

Based on the best model configuration, which includes capelin availability and fisheries catches as drivers, we explore potential scenarios for cod recovery. Since at the present time, this model does not incorporate uncertainty, these scenarios are merely illustrative in quantitative terms. However, they still provide an avenue to investigate the qualitative consequences of major changes in the drivers. Here we focus this exploration on the impact of capelin availability on the trajectory of Northern cod.

In 2003, DFO suggested that a possible conservation limit reference point (LPR) should be a spawning stock biomass (SSB) of 300kt (DFO 2003). Given the exploratory nature of this exercise, and in order to express this LPR in terms of total biomass (which is the variable in the model), we simply assume a 4:1 relationship between total biomass and SSB; this implies that an SBB of 300kt corresponds to a total stock biomass of 1200kt. As an illustrative exercise, here we explore when the model would reach this LPR level under two scenarios of capelin availability. The first scenario loosely corresponded to the conditions in 2009, with a nominal cod catches in the fishery of 3kt and a capelin acoustic index of 300kt. The second scenario corresponded to a similar size cod fishery, but reduced capelin availability (50kt). In both scenarios, catches and capelin were assumed constant over time, and the model was projected forward with those values.

The results suggest that, under constant 2009 conditions, Northern cod would reach the LPR level around 2019 (Fig 29a). However, if capelin availability is low, the stock is incapable of recovering to the LPR level (Fig. 29b). There are a considerable number of caveats to these results, and these timelines cannot be considered anything but an illustrative example of how different levels of capelin abundance can affect Northern cod dynamics. Furthermore, capelin levels change annually, so the actual trajectory of the stock, and the timelines to achieve any given LPR, would be variable and a function of the specific trajectory of capelin levels and the fishery. The low capelin level of 50kt considered in our scenario corresponded to the lowest observed level in the acoustic capelin survey during the 1990s (DFO 2008), but the most recent survey in 2010 was only 25kt, showing a dramatic decline form previous years (F. Mowbray,

pers. comm). If the results from this modelling exercise bear any resemblance with reality, not only could a depressed capelin stock pose a serious impediment to cod rebuilding, if it falls too low, it may put the mere survival of the cod stock at risk.

From the perspective of selecting and setting reference points, these results suggest that externalities to the stock, like capelin availability (or potentially other ecosystem-related features), may have a significant impact in the utility of purely stock-based reference points. Although it remains unclear which would be the best way of incorporating ecosystem effects into precautionary approach frameworks, the effectiveness of these management approaches may very well be highly dependent of our success at this task.

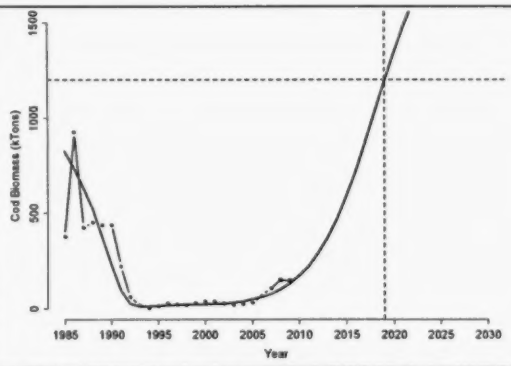
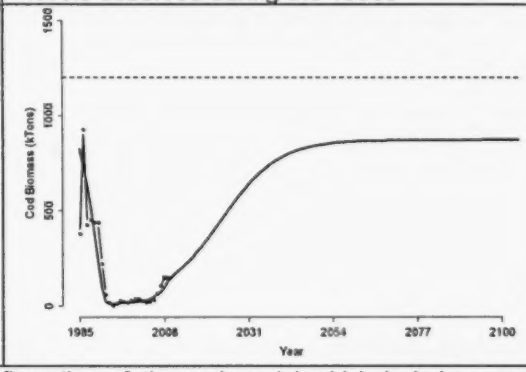
a) Projection assuming constant level of cod fishery and capelin availability; similar to those observed in 2009	b) Projection assuming constant level of cod fisheries similar to that observed in 2009, and reduced capelin availability to the minimum levels observed during the 1990s
	

Figure 29. Illustrative projections of the best configuration of the cod model which includes capelin availability and cod fisheries as drivers. The red line corresponds to the model output when actual annual capelin and fishery data are used as input; this period was the one used for estimating model parameters. The blue line corresponds to the projections assuming constant capelin and cod fishery levels. The conservation LPR at the total biomass level (horizontal dotted line) was simply set by assuming a 4:1 relationship with SSB.

Discussion

It was noted that the projections at high capelin availability seem very optimistic. Also the model seems to estimate quite a large carrying capacity.

The model uses a capelin index that is for Div. 3L only. The proportion of the northern cod stock is in Div. 3L is variable over time and this could add noise to the model result.

It was noted that the impact of capelin on cod in the model is not per capita ie a given amount of capelin in the model has the same impact regardless of the amount of cod. There was concern that this could imply that a given level of capelin biomass will result in the same growth rate in the cod population over a very wide range of cod biomasses. The meeting was concerned about the fact that size of the cod population has no impact on whether or not there are enough capelin.

Since 'impaired recruitment' can be used as the basis for the definition of an LRP there was some discussion of what this would be in a multispecies context. However, few multispecies models are age structured and so do not provide insight into this question.

The meeting agreed that the productivity of a stock is not something that occurs in isolation but is related to other components of the ecosystem, for example prey. Levels of prey (e.g. capelin) will affect the potential for populations to grow and sustain a fishery. However, studies have shown that MSY for a single species in a multispecies context is likely to be lower than that calculated in a single species context. LRP should be more conservative in a multispecies context.

DISCUSSION ON SETTING LIMIT REFERENCE POINTS

Plenary

Limit Reference Point for Northern cod

Based on a synthesis of the discussions leading up to this point, the group was prepared to table a proposed LRP for the Northern cod stock.

After the 1980's SSB for 2J+3KL has been lower and recruitment poor, indicating that the stock has been below a level where serious harm occurs. This stock is known to have episodic recruitment events and there were some low year classes in the 1980's. However, even these low recruitment episodes were well above subsequent recruitments.

Stock size is currently much smaller than it was historically. Survey SSB during the mid-1980's was 55 kg/tow and is the proposed LRP for this stock.

Discussions ensued on how this LRP would be presented, as results from SURBA+ or survey. However, it was the feeling that it does not matter since each of the formulations since all show the current population size to be about 10% of the LRP. Proposed presentations included:

- SURBA+ Kg/tow from the survey will be the units. 55 Kg/tow
- SURBA Estimate (swept area) 657 000 t
- VPA/survey q bump up 450 000 t
- Straight areal expansion of the survey index without modelling 400-450 000 t

The wording of the conclusions in the report in order to communicate appropriately the reasoning behind the limit reference point defined for Northern cod was discussed. Since the current model is SURBA+ it was decided to report the results from SURBA+.

Can the approach for 2J3KL cod be used for other cod stocks?

In considering the existing reference points for other Newfoundland cod stocks, and what they are based on, it was considered whether or not you could/would apply the Northern cod approach to other stocks.

$SSB_{recover}$ for 3Ps was determined and applied in 2004. However, there is no SR relationship for 3Ps cod, and therefore the 2J3KL approach is likely not useful.

Could determining a LRP for 3Ps be revisited using a SR approach or is there so little of a relationship that it cannot be done? It was suggested that a "random walk" approach may be applied here, followed by a discussion of which SR model might fit this stock. It was determined that since the historical performance of the fishery cannot be re-created because of suspicious catch information, we cannot drive a SR relationship.

Division 3NO cod

The current method for setting the LRP for 3NO cod is similar to that used here of 2J3KL cod and the LRP was considered to be appropriate.

GENERAL CONCLUSIONS ON REFERENCE POINTS

In referring to the document 'A fishery decision-making framework incorporating the Precautionary Approach' the meeting found it was not easy to interpret as it is in some places unclear and in others contradictory.

There is no unambiguous definition of an LRP from S/R if there is no depensation. It is necessary to reevaluate LRPs as appropriate, taking into account the longevity of the species. There may be changes in stock dynamics, model input and/or model or formulation used that make this reevaluation necessary.

If using a SR model for determining the LRP best practice dictates that the significance of fitted models be assessed by testing against two null models (constant recruitment or constant recruitment rate). It is not advisable to extrapolate model results - especially the LRP - beyond the range of observations. An accepted parametric or smoothed SR model should be both biologically and statistically defensible.

Recruitment describes only part of the productivity of the stock and other factors (growth, maturity, fecundity, mortality) are also important. All aspects of productivity need to be considered when determining removal rates. However they may not all be needed to define regions of "serious harm". For example, if a domain of biomasses were identified that showed compromised recruitment, that alone should be used to define a LRP.

Differences in productivity over time are evident in many stocks. It is important to understand the causes of these changes and which components of productivity are changing. There has been little research into appropriate ways of taking changes in productivity into account in the setting of biological reference points such as LRP.

The productivity of a stock does not occur in isolation but is related to other components of the ecosystem, (predator, prey and competitors). Levels of prey (e.g. capelin) will affect the potential for predator populations (e.g. cod) to grow and sustain a fishery. Studies have shown that you can't remove single species MSY for all species simultaneously in an ecosystem of interacting species. The current DFO PA framework is based on a single species concept and needs to be extended to an ecosystem context and appropriate ecosystem based reference points derived.

Northern cod comprises a number of spawning components. Loss of spawning components can alter stock productivity. It is not clear how to incorporate loss of stock components into the definition of LRPs.

It was noted that some other jurisdictions (USA, ICES) are moving away form LRP (see section on frameworks in other jurisdictions above).

CONCLUSIONS ON REFERENCE POINTS FOR NEWFOUNDLAND COD STOCKS

2J3KL (Northern) cod

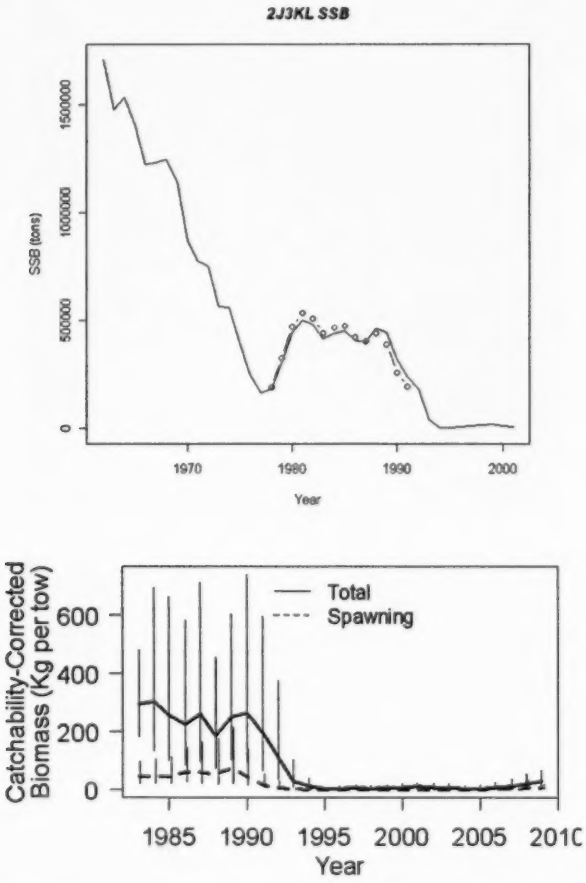


Figure 30. Spawning stock biomass for 2J3KL cod from a VPA extending the last accepted assessment (Shelton and Lilly, 2000; Shelton et al., 2006, top) and from the SURBA model presented at this meeting (bottom). Together these show the trend in SSB over time in this population.

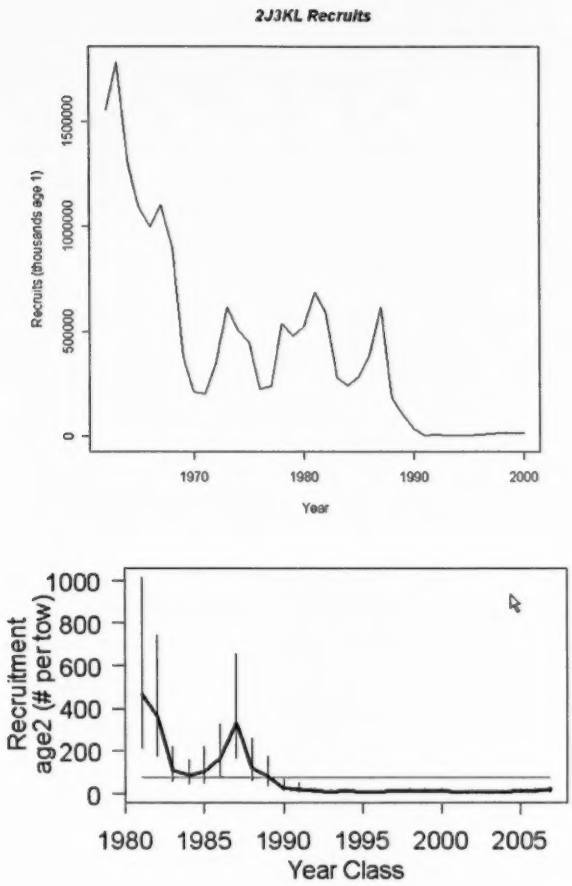


Figure 31. Recruitment for 2J3KL cod from a VPA extending the last accepted assessment (Shelton and Lilly, 2000; Shelton et al., 2006, top) and from the SURBA model presented at this meeting (bottom). Together these show the trend in recruitment over time in this population.

The 2J+3KL cod spawner biomass and recruitment remain at extremely low levels compared to the 1960's. SSBs in the 1980's were the last to produce medium levels of recruitment. After the 1980's SSB has been low and recruitment poor, indicating that the stock has been below a level where serious harm occurs. The average SSB during the 1980's is considered as the limit reference point for 2J+3KL cod. The stock is currently estimated to be at 10% of this LRP. The model spawning stock during the 1980s' was 55 Kg per tow or 660 000 t. Recent estimates of total mortality have been lower than the very high levels experienced by 2J+3KL cod from 1996 to 2003, thus establishing a LRP based on the low productivity period is not appropriate for this stock. This LRP should be reevaluated once more data, particularly at higher stock sizes, are available.

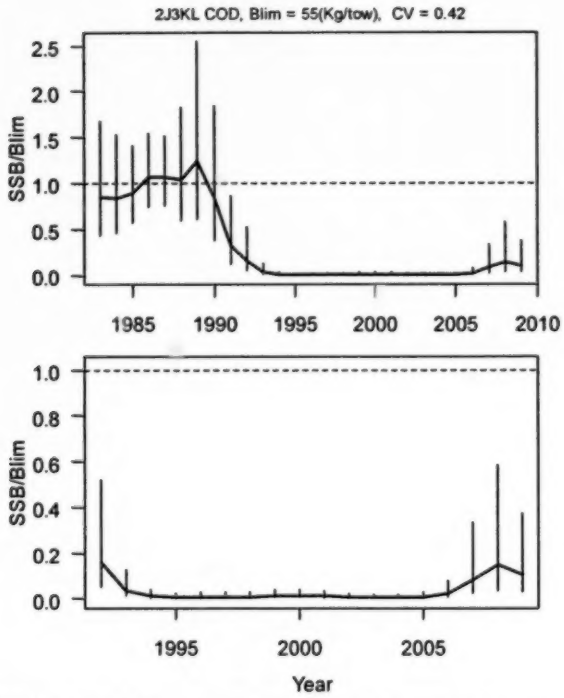


Figure 32. The ratio of SSB/Blim for 2J3KL cod from the SURBA presented at this meeting. The top panel is for the entire period in the model, the bottom for the period since 1992.

3Ps cod

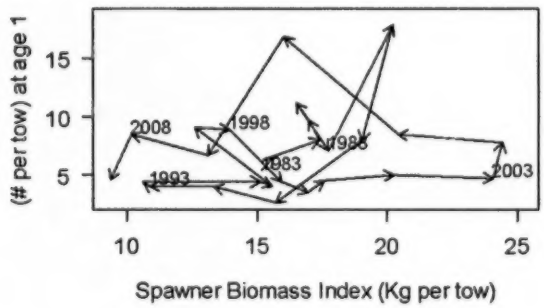


Figure 33. Recruitment and Spawner biomass for 3Ps cod

At the moment data used in the assessment for 3Ps cod begin in 1983 and there is little indication of a stock recruit relationship for this stock over this time period. Therefore, the method used for 2J+3KL cod may not apply at this time. The LRP of Brecover is still considered to be appropriate, with the year from which recovery occurred being 1994. However it is recommended that the SURBA model incorporating a random walk be tested on this stock and that consideration should be given to incorporating data from the AT Cameron survey series in order to extend the time series for this assessment. In addition it is recommended that methods

be explored to extend the time series even further using the age composition of the commercial catch.

3NO cod

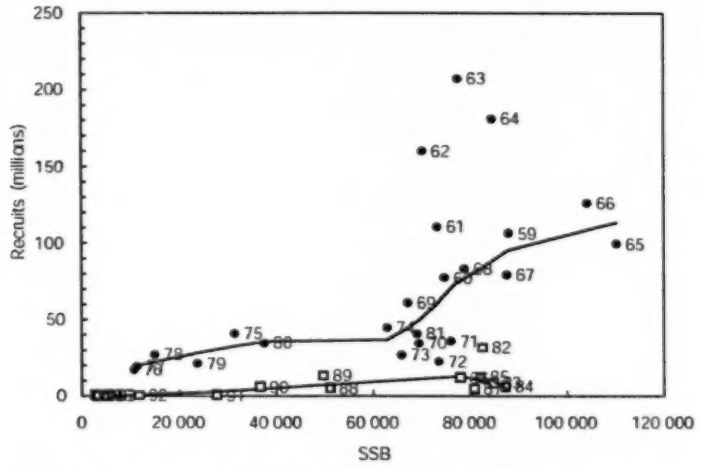


Figure 34. Recruitment and spawner biomass for 3NO cod

The method used in setting the LRP for 3NO cod has the same conceptual basis as that used for 2J+3KL cod. In both cases the stock recruit scatter has been examined to determine the point below which only poor recruitment has consistently occurred i.e. serious harm. The LRP of 60 000 t SSB is considered appropriate for this stock.

Removal reference: To be consistent with the UN agreement on highly migratory and straddling stocks the removal reference should not exceed Fmsy or a suitable proxy.

Upper stock reference: The USR should be such that a stock in the healthy zone has have a low probability of actually being below the LRP. It is proposed for 2J+3KL cod that it be based on the lower 95% set confidence limit from the distribution of SSB divided by the LRP. For 2J+3KL it should be ***at least*** 95 kg per tow (1.12 million tons). For 3Ps it should be at 1.5 times the LRP and should be ***at least*** 16 kg per tow (sss tons). For both stocks these are indices and not in absolute stock size. These USR should be reviewed as more data become available. There is no USR for 3NO cod.

Target reference: This should be high enough that fishing at the removal reference will have a low probability of moving the stock into the cautious zone. A generally accepted default target under the precautionary approach is B_{msy} or above.

The status of the stock relative to these reference points suggest a course of management action. A stock will be less likely to fall below the LRP if management action to rebuild the stock is taken once the stock falls below the USR but well before it reaches the LRP.

MEETING PROCEEDINGS – PROJECTION METHODS

The initial discussions on long-term projection methods, of population abundance, for cod stocks involved the Designated Units (DUs) and how to best approach each projection. A lot of discussion was generated about how to go about a DU based projection given that each stock with a DU is a different population. Each DU has stocks using survey-based and VPA-based assessments. Recruitment, growth, maturity, mortality, fishery selectivity and stochasticity must all be considered for projections. Projections could be performed under different productivity levels implying different recruitment, as well as different growth, maturity, etc.

POPULATION METRICS TO BE CONSIDERED FOR PROJECTIONS

It is apparent that there is autocorrelation in many of the metrics that are used in projections. However, how to quantify the autocorrelation and use it in projections is not clear – as the processes involved are usually not well enough known to quantify. Nonetheless this should be taken into account in some way.

It is anticipated that the conditions in the near future should be similar to recent conditions, but that conditions may deviate from recent as time goes on. An 'expanding window' resampling strategy was suggested, discussed, and decided upon to account for this. As each year of projection is added an additional year of data is added to the pool from which values can be randomly resampled with replacement starting with the most recent and moving backwards in time. This means that the first few years of the projection samples from the most recent data. It also means that we assume that the stock conditions will have an increasing probability of being like the past conditions as the selection window expands into the past. The randomly selected year will be the same for each attribute. There has to be the consideration that once application of these processes is applied, technical difficulties may arise, but the general approach will be applied as strictly as possible for each stock.

Many components of a stock would have to be restored in order to return to historical spawning capabilities. There may be an idea of what these were but it is unknown if they can be reached again. Loss of spawning components can alter productivity. It is not clear how to incorporate the loss of a stock component into the projections or definition of LRPs.

Recruitment is best looked at using a stock-recruit (s/r) curve although one does not exist for some cod stocks. Fitting a s/r curve to the upper and lower 1/3 of data will allow projections under different levels of productivity. In cases where a s/r does not exist, it was decided that a poorly fit Ricker, through the origin, would form a better s/r relationship than an average since an average recruitment could lead to problems 30 years in the future. Different curves can be used for different stocks and this decision will be made by the scientist performing the work. To perform projections under high productivity the average recruits-per-spawner (rps) can be used and for low productivity use the average recruitment. The recruitment will be modeled using the appropriate curve with resampling from the residuals. At the time of the meeting it was proposed that use of a smoother, over a mixed Beverton-Holt fitting, be investigated.

There is a high likelihood that recruitment may be generated from a SSB that is outside of any stock observations. In these cases would it be better to extend the s/r curve or is there another way around this? It was proposed that to the right of the cloud go with the mean or an asymptotic line, or estimate for S/R curve, and if to the left draw a line to the origin. Accompany these instances with a report of how often this occurs. It is not advisable to extrapolate model

results, especially the LRP, beyond the range of observations. An accepted parametric or smoothed s/r model should be biologically and statistically defensible.

Growth is not modeled in the stocks under discussion but is fairly well defined. There is a significant change in weights at age on a division by division basis. Ideally there should be a time series model fit to weight at age and the correlation structure should be used to inform the projections. In the absence of this, it is proposed to randomly select a year and resample from the observations, with the zeros filled with averages and use the observations for the ages in that year.

Maturity is analyzed by estimating the proportion mature at age, by cohort. There is a statistical relationship between maturities and population sizes but this relationship has not been quantified. There is an issue about resampling by cohort in that it may be better to keep good and bad cohorts together and move those around, rather than moving years around so that the jumbling variable will be the cohort. Because future years are more likely to be like the recent past than far in the past, an 'expanding window' resampling strategy will force a recent year to be selected in the first years of the projection, where, as time passes, the resampling will be more random.

Mortality generated a lot of discussion as the stocks that are assessed with a VPA have estimates of natural mortality (M) while those that are assessed with SURBA have estimates of total mortality (Z). While the moratorium period should have had a very low fishery mortality (F), there may have been a small amount in some years due to a high bycatch and recreational fisheries. In most stocks it is a safe assumption that M=0.2 unless otherwise known. There are indications that some stocks, which only have Z estimates, suffer a significantly different M and it is unreasonable to assume M=0.2.

There was some discussion generated about the concern that subtracting M from Z would lead to negative F estimates. Years in which that happens should be omitted. For SURBA based assessments the only option is to do F=0 projections even though the future F will not likely be zero. This may show the maximum potential for recovery. F could be incorporated given certain assumptions about M.

Fishery selectivity must be considered for performing projections. A constant partial recruitment (PR) (which may be the long term average) could be used but patterns should be examined for each stock before deciding whether to use a long term average or to use some variation in partial recruitment. The relationship between the catch and Z is unknown and catch data are either too unreliable or unavailable for use in the assessment. However, it was concluded that using PR from periods while stocks are under moratorium should be avoided.

For **population numbers**, if there is a distribution of starting numbers from the projection then draw from it. The plus sized group should be considered where appropriate.

AGREED APPROACH TO PROJECTIONS

Resampling strategy:

It is anticipated that the conditions in the near future should be similar to recent conditions, but that conditions may deviate from recent as time goes on. An 'expanding window' resampling strategy was decided upon to account for this. As each year of projection is added an additional year of data is added to the pool from which values can be randomly resampled with replacement starting with the most recent and moving backwards in time. This means that the first few years of the projection samples from the most recent data. It also means that we assume that the stock conditions will have an increasing probability of being like the past conditions as the selection window expands into the past. The resampling is done by picking a year at random and then using all the data (weights, maturities, natural mortality) in that year as all of these metrics are likely to be interrelated. Recruitment will also be based on that randomly resampled year but in a different fashion. Since recruitment is related to SSB this must be taken into account. Recruitment will be generated from the SSB in the projection year through the application of a stock appropriate stock recruit curve and adjusted by the residual from that curve taken from the year randomly picked in the resampling. Results should report how often recruitment is generated from SSB that are outside of the range of the data used to generate the stock recruit curve as this may be problematic (extrapolating outside the data).

For current conditions: the moving window strategy chosen for projections emphasizes current conditions. Unless 'current' is defined more clearly then this is the approach that will be used and separate current condition projections will not be attempted.

For projections under different productivity: the resampling of each of the components will produce a range of results. The upper, lower and mid range of the results will be used to get high, low and medium productivity. These are not strictly different levels of productivity but will give the expected range of results. They could perhaps be referred to as optimistic, average and pessimistic conditions.

Natural Mortality: greater discussion was given to assumptions about M in the projections. It was decided to resample M in the same fashion as other factors. Not all stocks have estimates of M other than the 0.2 assumption. It was decided that if there are no estimates of M then M will be 0.2 throughout the projection. For stocks with estimates then M will be the estimate in the resampled year (as above). For 2J+3KL cod there is indication from the survey data in the moratorium period that M has increased but its exact level is unknown. M also appears to have dropped to lower levels in the most recent years. Therefore, for this stock it was decided to resample from the moratorium period using Z from SURBA adjusted by the one estimate of F during this time is that F=0.06 (from tagging) as an estimate of M. The level of M is not known for the 1983 to 1992 period but is thought to be lower. For this period M will be set lower with the exact level to be determined. Possible approaches include setting M at 0.2, sampling from a distribution centered on 0.2, or to use life history invariants to provide an estimate of M for this time period.

Fishery selectivity: patterns should be examined for each stock before deciding whether to use a long term average or to use some variation in partial recruitment. However, it was decided that using PR from periods while stocks are under moratorium should be avoided.

Population numbers: if there exists a distribution of starting numbers from the projection then draw from it in order to include uncertainty in the starting numbers. The +group should be considered if appropriate.

It was noted that there will be a meeting in Moncton Dec 6-8 (Atlantic Cod Framework Meeting: Assessment Models, Medium-term Projections, Reference Points) which will also discuss projection methodology and that the approach agreed upon here may be updated with the results of that meeting.

METHODS FOR COMBINING POPULATIONS INTO DESIGNATED UNITS (DUS)

Performing projections on an entire DU is complicated since each stock within it is a separate population with only some mixing issues. For this reason, it will be necessary to perform modeling on each stock separately before combining the results and proposing a recovery strategy for the DU. However, there still may be issues with this approach as some stocks within a DU could have a different status. The general feeling of meeting participants was that combining stocks and long term projections are both questionable practices. Two main questions were raised in these discussions.

1. **Should populations be combined or projected separately and then combined?**

The stocks are managed and assessed as separate populations because they are thought to have (for the most part) independent population dynamics. Combining the projection results into DUs is a questionable process for this reason and also because there is not a totally satisfactory way to quantitatively do so. In addition, stock specific results are likely to be more useful to fisheries managers. It was decided that projections should be conducted on each stock separately and results combined for the stocks in a DU. Stock-specific, as well as DU results, should therefore be presented.

2. **How do you combine two populations which are modeled using different approaches?**

Projection esults for a DU need to be produced by combining the stock specific results. They should be combined in such a way that appropriate weight is given to each stock. A stock that was the historically larger one in the DU should be given more weight than the one that was the smaller one.

To produce projection results for DUs the stock specific results will be combined using a weighted average. A number of different weightings (area weighting, landings, stock size) were considered. All weightings considered have drawbacks and an element of arbitrariness but are each an attempt to weight by the relative maximum stock sizes. It was decided that the best at this time is perhaps based on an average of peak swept area estimate of SSB, either from the survey or from q derived survey, back into the mid 1980's (as far as the data are common for the stocks making up a DU). Once a weighting is decided upon for combining stocks within a DU then it will be relatively easy to calculate a weighted average of the ratio of stock size to the reference point.

It should be noted that there was a strong conclusion that there are so many assumptions in long term projections that their utility is highly questionable.

Initial projections for 2J+3KL cod and 4VsW cod were reviewed to ensure that the chosen method of resampling for projections did not cause any problems. Results indicated that the method can be successfully implemented.

REFERENCES

ADMB Project. 2009. AD Model Builder: automatic differentiation model builder. Developed by David Fournier and freely available from admb-project.org.

Baird, J.W., Bishop, C.A., Brodie, W.B. and Murphy, E.F. 1992. An assessment of the cod stock in NAFO Divisions 2J3KL. CAFSAC Res. Doc. 92/75, 76p.

Brattey, J., Cadigan, N.G., Dwyer, K., Healey, B.P., Morgan, M.J., Murphy, E.F., Maddock Parsons, D., and Power, D. 2011. Assessment of the cod (*Gadus morhua*) stock in NAFO Divisions 2J+3KL in 2010. DFO Canadian Science Advisory Secretariat Research Document 2010/103. viii + 108 p.

Cadigan, N. G. 2010. Trends in Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps Cod (*Gadus morhua*) stock size based on a separable total mortality model and the Fisheries and Oceans Canada Research Vessel survey index. DFO Canadian Science Advisory Secretariat Research Document 2010/015.

DFO. 2003. Northern (2J+3KL) cod Stock Status Update. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2003/018.

DFO. 2008. Assessment of capelin in SA 2 + Div. 3KL in 2008. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/054.

Shelton, P.A. and Lilly, G.R. 2000. Interpreting the collapse of the northern cod stock from survey and catch data. Can. J. Fish. Aquat. Sci. 57:2230-2339.

Shelton, P.A., Sinclair, A.F., and Chouinard, G.A., Mohn, R. and Duplisea, D.E. 2006. Fishing under low productivity conditions is further delaying recovery of Northwest Altnatic cod (Gadus morhua). Can. J. Fish. Aquat. Sci. 63:235-238.

Skaug, H. J. and D. A. Fournier, 2006. Automatic approximation of the marginal likelihood in non-Gaussian hierarchical models. Computational Statistics & Data Analysis 51, 699-709.

APPENDIX 1 – TERMS OF REFERENCE

Atlantic Cod Framework Meeting: Reference Points and Projection Methods For Newfoundland Cod Stocks

Battery Hotel and Conference Center, St. John's, NL
November 22-26, 2010

Chairperson: Joanne Morgan

Context

The Precautionary Approach (PA) is a general philosophy to managing threats of serious or irreversible harm where there is scientific uncertainty. The application of precaution requires increased risk avoidance where there are risk of serious harm and high uncertainty. These conditions often apply in fisheries; therefore precaution should be incorporated in fisheries management.

Canada is committed domestically and internationally to the use of PA in managing its fisheries. Over the last few years, there have been several initiatives in Canada to define the PA in a fisheries context, to identify benchmarks that would be consistent with the approach and to apply it in fisheries management. The fundamental principles guiding this approach have been outlined in two key documents produced by DFO: 1) the Science Advisory Report 2006/023 that identifies the minimal requirements for harvesting strategies to be compliant with the PA (http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_023_E.pdf) and 2) the 2008 Decision-Making Framework Incorporating the Precautionary Approach (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm); a policy document to guide the incorporation of PA principles in the management of Canadian fisheries.

To be compliant with the PA, fishery management plans should include harvest strategies that incorporate a science-based Limit Reference Point (as well as Upper Stock Reference and Removal Reference points). It is expected that the management decisions should respect the indicated actions in each of the stock zones in relation to these points (i.e., Healthy, Cautious, and Critical).

Besides activities in support of the PA for Atlantic cod at this time, science input will also to be required for the Recovery Potential Assessment of several COSEWIC Designatable Units (DUs) of Atlantic cod in February 2011. In anticipation of this, a number of modeling and analysis questions must be reviewed before providing projections of abundance by DU.

Objectives

The key objective of the meeting is to define limit reference points, consistent with the precautionary approach, for Newfoundland cod stocks based on the best scientific information available, including that from the last assessment of these stocks as well as past assessments of the stock. Approaches to address projections required for the Recovery Potential Assessment of cod stocks will also be discussed.

No advisory reports are expected from the meeting since no catch or management advice will be produced.

Specifically, the following objectives have been set:

1. Peer review of approaches for the development of limit reference points, including:
    - Review reference point methodologies and propose approaches for the identification of reference points for Newfoundland cod stocks.
    - Apply the chosen methodology(ies) to estimate the reference points, as per the decision-making framework developed by DFO for the application of Precaution in this fishery, for Newfoundland cod stocks.
2. Peer review of approaches for conducting long-term projections of population abundance, including:
    - Review methodologies for conducting projections of population abundance for Newfoundland cod stocks.
    - Review methodologies for combining stock projections to the COSEWIC DU level.

Products

A Proceedings Report will be produced to record the meeting discussions and outcomes.

Participation

This meeting will be highly technical in nature and the discussions and review will require participants that are familiar with a broad range of quantitative assessment and modeling techniques. Since no catch or management advice will be provided, the perspectives and participation from industry, aboriginal communities, and provincial governments are not required. Participation will be internal and by invitation only.

APPENDIX 2 - AGENDA

Anchor Room
Battery Hotel and Suites, 100 Signal Hill Rd., St. John's, NL
November 22-26, 2010

Chairperson: Joanne Morgan

Limit Reference Points

Monday Nov. 22

0900	**Opening remarks**	Joanne Morgan
	DFO's decision making framework incorporating the precautionary approach	Peter Shelton
	A review of frameworks from some other jurisdictions	Peter Shelton
	Methodologies for setting LRPs (a review)	Daniel Duplisea
	Methodologies for setting LRPs in Atlantic Halibut and Haddock	Bob Mohn
	LRPs in other cod stocks	
	• 3NO	Don Power
	• 3Ps	Brian Healey
	• 4RS3Pn	Daniel Duplisea
	• 4T	Joanne Morgan
	• 4VsW	Bob Mohn
	Limit reference point for 2J3KL cod	
	• Surba+ and reference points for 2J3KL cod	Noel Cadigan
	• Historical perspective on MSY-based reference points	Peter Shelton

Tuesday Nov. 23

0900	**Limit reference point for 2J3KL cod (cont'd...)**	
	Ecosystem considerations for LRPs	Mariano Koen-Alonso
	Can approach for 2J3KL cod be used for other cod stocks?	Plenary
	Discussion of challenges for setting LRPs	Plenary

Discussion of other reference points for 2J3KL cod (upper stock reference, target reference, removal reference). Plenary

DUs and projections

Note: this portion of the meeting is still very fluid and will mainly include discussions on factors to take into account and decisions on how to proceed.

Wednesday Nov. 24 – Friday Nov 26 (0900-1700)

Discussion of considerations for doing long term projections Plenary

- Recruitment
- Growth
- Maturity
- Stochasticity including process error

Discussion of methods for combining populations into DUs Plenary

- Should they be combined or projected separately and then combined
- How do you combine 2 populations which are modeled using different approaches

APPENDIX 3 - PARTICIPANTS

Name	Affiliation	Email
Alain Frechette	DFO Science – QC Region	alain.frechet@dfo-mpo.gc.ca
Daniel Duplisea	DFO Science – QC Region	daniel.duplisea@dfo-mpo.gc.ca
Bill Brodie	DFO Science – NL Region	bill.brodie@dfo-mpo.gc.ca
Nadine Templeman	DFO Science – NL Region	nadine.templeman@dfo-mpo.gc.ca
Ben Davis	DFO Science – NL Region	ben.davis@dfo-mpo.gc.ca
Rick Rideout	DFO Science – NL Region	rick.rideout@dfo-mpo.gc.ca
Don Stansbury	DFO Science – NL Region	don.stansbury@dfo-mpo.gc.ca
Dawn Maddock-Parsons	DFO Science – NL Region	dawn.parsons@dfo-mpo.gc.ca
Don Power	DFO Science – NL Region	don.power@dfo-mpo.gc.ca
Peter Shelton	DFO Science – NL Region	peter.shelton@dfo-mpo.gc.ca
Noel Cadigan	DFO Science – NL Region	noel.cadigan@dfo-mpo.gc.ca
John Brattey	DFO Science – NL Region	john.brattey@dfo-mpo.gc.ca
Brian Healey	DFO Science – NL Region	brian.healey@dfo-mpo.gc.ca
Mariano Koen-Alonso	DFO Science – NL Region	mariano.koen-alonso@dfo-mpo.gc.ca
Bob Mohn	DFO Science – Mar Region	bob.mohn@dfo-mpo.gc.ca
Dario Lemelin	DFO FAM – QC Region	dario.lemelin@dfo-mpo.gc.ca
Dave Coffin	DFO FAM – NL Region	dave.coffin@dfo-mpo.gc.ca